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EVALUATION OF SOIL RESISTANT COATINGS FOR EXTERIOR AIRCRAFT SUR--ETC(U)
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EVALUATION OF SOIL RESISTANT COATINGS FOR EXTERIOR AIRCRAFT SURFACES

See 1473 in back

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2 JUNE 1977

FINAL REPORT
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Prepared for
NAVAL AIR SYSTEMS COMMAND
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Washington, D.C. 20361

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APPROVED BY: P M Sturm DATE: 2 June 1977

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S U M M A R Y

INTRODUCTION

The Naval Air Systems Command has shown considerable interest in crosslinked fluoropolymer coatings developed by the Naval Research Laboratory, Washington, DC as a protective finish for the exterior surfaces of naval aircraft. Naval Research Laboratory publications (see references (a) and (b)) outline the unique properties of these coatings, which are reported to exhibit superior resistance to heat, light, chemicals, soil and corrosion, with surface energies approximating the magnitude of polytetrafluoroethylene (TEFLON*).

The purpose of this investigation, conducted under AIRTASK/Work Unit A03V3200/001B/GE24290000,was to evaluate the Naval Research Laboratory (NRL) coatings as possible candidate finishes for application to the exterior surfaces of naval aircraft.

Tests were conducted to compare the NRL pigmented coatings with the standard Navy MIL-C-81773B linear urethane coatings currently being utilized as the exterior protective topcoat on naval and marine aircraft. The standard corrosion inhibitive primer meeting military specification MIL-P-23377C requirements was utilized as the primer finish for all of the laboratory tests.

Tests were also conducted to determine the chemical and soil resistant properties of the clear NRL fluoropolymer coating when applied as a protective overlay to the Navy acrylic MIL-L-81352A, epoxy polyamide MIL-C-22750B, and linear urethane MIL-C-81773B topcoat finishes.

SUMMARY OF RESULTS

The NRL pigmented coating, when applied as an exterior protective coating to epoxy primed test panels, was found to be:

- equal to the MIL-C-81773B coating for primer to topcoat adhesion.
- lower than the MIL-C-81773B coating in initial gloss.
- equal to the MIL-C-81773B topcoat for heat resistance (non-yellowing) properties.
- equal to the MIL-C-81773B topcoat for hot engine oil and lubricating oil resistance properties.
- equal to the MIL-C-81773B topcoat as a corrosion protection finish when subjected to the NaCl-SO_2 exposure and filiform corrosion tests.
- inferior to the MIL-C-81773B topcoat for soil releasing properties based on the soil removal test outlined in military specification

* DuPont Trademark

MIL-C-46316 and the experimental NADC carbon removal test.

- equal to the MIL-C-81773B topcoat when subjected to the mandrel bend and G.E. Impact test conducted at room temperature and at -60°F (-51°C).

- equal to the MIL-C-81773B topcoat for gloss retention properties when subjected to the Florida exposure and XW Weatherometer tests.

The NRL clear coating, when applied as a clear protective overlay coating, was found to be:

- equal to the MIL-C-81773B clear topcoat when subjected to the mandrel bend and G.E. Impact tests conducted at room temperature and at -60°F (-51°C).

- equal to the MIL-C-81773B clear topcoat for gloss retention properties when subjected for 600 hours to the Atlas Weatherometer.

- superior to the MIL-C-81773B clear topcoat in non-yellowing (ageing) properties

CONCLUSIONS

The overall chemical and physical properties of the standard Navy linear urethane pigmented topcoats formulated to specification MIL-C-81773B requirements, are equal or superior to the NRL developed fluorinated polyepoxy and polyurethane pigmented topcoat finishes.

The NRL clear fluorinated coating, however, was found to be slightly superior to the standard MIL-C-81773B clear coating. When subjected to accelerated weatherometer exposure tests, the NRL clear coating exhibited superior ageing (non-yellowing) properties.

Laboratory soil removal tests show that the NRL fluorinated coatings, both clear and pigmented, did not exhibit soil removal properties superior to those inherent in the standard specification MIL-C-81773B linear urethane coatings.

RECOMMENDATIONS

It is recommended that the linear polyurethane coatings meeting specification MIL-C-81773B requirements be retained as the standard durable and weather resistant topcoat finishes on exterior surfaces of Naval and Marine aircraft. An overall review of comprehensive evaluation data, obtained by comparing the NRL fluorinated with the specification MIL-C-81773B coating systems, does not offer advantages sufficient to warrant a change to the NRL fluorinated topcoats.

Another factor is the cost of the 3-component NRL fluorinated coatings which can be conservatively estimated to be initially in the range of two-hundred to three-hundred dollars a gallon, as compared to a current price of fifteen to twenty dollars a gallon for the MIL-C-81773B specification coatings.

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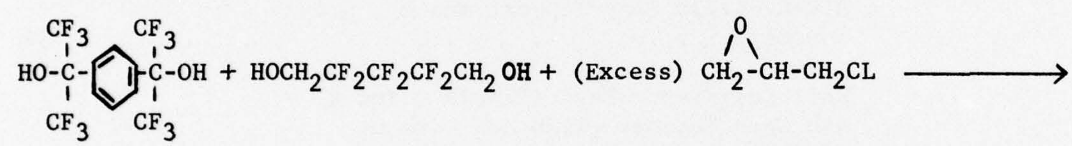
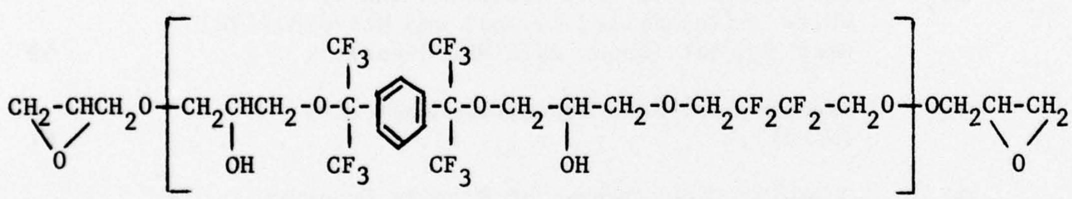
The Naval Research Laboratory, Washington, DC has developed a fluorinated polyepoxy polyol that can be converted by chemical reaction in situ into a continuous coating of a thermosetting nature. The coating is made from a fluorinated aliphatic and aromatic diol condensed with epichlorohydrin to produce fluorinated polyols. The soluble polyol is then crosslinked with a commercially available polyisocyanate to form a tough and durable coating. The unique soil and corrosion resistant properties of this coating, described in references (a) and (b), are of considerable interest to the Naval Air Systems Command, Washington, DC.

Designated as a complex organic polymeric compound, the NRL coating, as illustrated in reference (a), is prepared by reacting 1,3-bis (2 hydroxyhexafluoro-2-propyl) benzene (DIOL I) and hexafluoropentanediol (DIOL II) with an excess of epichlorohydrin to form the diepoxide (DIOL III).



DIOL I DIOL II EPICHLOROHYDRIN



DIOL III DIEPOXIDE (HIGH MOLECULAR WEIGHT POLYOL)

The high molecular weight adduct (DIOL III), upon addition of a polyisocyanate crosslinking agent and a catalytic agent, cures at room temperature to a durable chemical and corrosion resistant coating. The three-component coating, mixed in the proper volume ratios, can be easily applied to the desired film thickness using commercially available paint spray equipment.

To determine the merits of the NRL coatings for use on naval aircraft, the physical and chemical properties of the coatings were compared with the standard linear polyurethane topcoats meeting specification MIL-C-81773B, which are currently utilized as the basic exterior finish for naval aircraft. Tests to which the topcoats were subjected were those necessary to obtain data considered to be most important for the type of operational environment in which carrier based naval aircraft operate.

The fluorinated coatings, pigmented and clear, utilized for testing, were synthesized on a laboratory scale by the Naval Research Laboratory, Washington, DC. Because of the high cost and limited supply of the experimental coatings, laboratory tests were selective and carefully planned. The high cost of the fluorinated coatings can be attributed to the fluorinated precursor (hexafluoroacetone), which is very expensive ($213/gallon) and the chemical procedures required to synthesize the diepoxide, which is designated, for identification purposes, as Component I. Component II, designated as the crosslinking agent, is a clear polyisocyanate solution similar to the Part II component utilized for crosslinking the standard MIL-C-81773B coating. The catalytic agent, designated as Component III, is a solution of dibutyl tin dilaurate. Component II (crosslinking agent) and Component III (catalytic agent) are readily available from commercial manufacturers at a reasonable cost to the coatings formulator.

When evaluating the NRL fluorinated polyepoxy and polyurethane polymeric coatings, emphasis was placed on the following coating tests:

1. Chemical resistance to aircraft hydraulic and lubricating oils currently being utilized on Naval and Marine aircraft, as well as high temperature hydraulic and lubricating fluids projected for use on future aircraft.

2. Accelerated $NaCl-SO_2$ exposure tests to determine the corrosion resistant properties of the coatings when applied to carrier based aircraft exposed to extensive amounts of salt spray and (SO_2) stack gases.

3. Low temperature flexibility tests to determine the resistance of the topcoat finishes to cracking when applied to fastener pattern areas of high speed-high altitude aircraft.

4. Heat resistance and yellowing properties of the coatings when subjected to temperatures experienced on skins adjacent to engine exhaust and guns.

5. Weathering properties of the coatings when subjected to laboratory tests using the open arc weatherometer, as well as outdoor exposure studies conducted at the Florida seacoast testing site.

The majority of the chemical and physical tests to which the coatings were subjected were selected from military specification MIL-C-81773B Coating, Polyurethane, Aliphatic, Weather Resistant. Tests, considered to be of significant importance, but not included in specification MIL-C-81773B, were also conducted to obtain data on chemical resistance, low temperature impact flexibility, accelerated corrosion, heat stability and soil removal properties.

COATING APPLICATION DATA

APPLIED COATINGS

Prior to applying the selected topcoat finishes, one coat of corrosion inhibitive primer meeting military specification MIL-P-23377C was applied to all of the test panels described in this report.

The exterior topcoat finishes subjected to extensive laboratory testing were the pigmented NRL fluorinated polymer coatings, and the standard Navy MIL-C-81773B linear urethane coatings. Two other Navy specification topcoats, designated as acrylic lacquer meeting military specification MIL-L-81352A and epoxy polyamide meeting military specification MIL-C-22750B, were also selected to obtain comparable data on soil removal properties and gloss retention properties. A set of acrylic and epoxy topcoated panels, as standards, were compared to a set of acrylic and epoxy topcoated panels sprayed with an overcoat of the NRL clear fluorinated polymer coating.

The primer coat and topcoat finishes selected for testing are as follow:

Epoxy Polyamide Primer, MIL-P-23377C (2-component kit)
Component I - pigmented base (epoxy)
Component II - clear converter (polyamide)

MIX RATIO: 1 to 1 (by volume)

Linear Polyurethane Topcoat, MIL-C-81773B (2-component kit)

Component I - pigmented base (polyester)
Component II - clear converter (polyisocyanate)

MIX RATIO: 1 to 1 (by volume)

NRL Fluorinated Polyepoxy and Polyurethane Topcoats
(Clear and Pigmented)

Component I - pigmented or clear fluorinated resin solution
Component II - clear isocyanate solution
Component III - clear catalyst solution

MIX RATIO: 4 to 2 to 1 (by volume)

Epoxy Polyamide Topcoat, MIL-C-22750B (2-component kit)

Component I - pigmented base (epoxy)
Component II - clear converter (polyamide)

MIX RATIO: 1 to 1 (by volume)

Acrylic Lacquer Topcoat, MIL-C-81352A (1-component)

SUBSTRATE TEST PANELS

Flat aluminum test panels measuring 3 x 6 x 0.020 in. (7.62 x 15.24 x 0.05 cm) were used for all of the coating tests with the exception of the Florida exposure test panels, which measured 5 x 16 x 0.20 in. (12.70 x 40.64 x 0.05 cm), and the fastener test panels used for the $NaCl-SO_2$ exposure test which measured 5 x 8 x 0.125 in. (12.70 x 12.32 x 0.317 cm).

The aluminum alloy test panels and the chemical conversion and electrolytic coatings selectively applied to the test panels are designated as follows:

Specification MIL-C-5541B, Class 1A treated 2024 bare and 2024 clad.

Specification MIL-C-8625C,Type II (Sulfuric acid anodized) 2024 bare and 2024 clad.

Specification MIL-A-8625C, Type I (Chromic acid anodized) 2024 bare and 2024 clad.

Specification MIL-C-8625C, Type II, Class I (Sulfuric acid anodized and 5 percent dichromate seal) 2024 bare and 2024 clad.

Specification MIL-C-5541B, Class 1A treated 7075 bare and 7075 clad.

Specification MIL-C-8625C,Type II (Sulfuric acid anodized) 7075 bare and 7075 clad.

Specification MIL-A-8625C, Type I (Chromic acid anodized) 7075 bare and 7075 clad.

Specification MIL-C-8625C,Type II, Class 1 (Sulfuric acid anodized and 5 percent dichromate seal) 7075 bare and 7075 clad.

The aluminum alloys designated as 2024 bare and 2024 clad meet Federal Specification QQ-A-250/4 and QQ-A-250/5, respectively. The aluminum alloys designated as 7075 bare and 7075 clad meet Federal Specification QQ-A-250/12 and QQ-A-250/13, respectively.

APPLICATION OF COATINGS

The epoxy polyamide primer, prepared as specified in military specification MIL-P-23377C, was spray applied to the test panels to a film thickness of 0.6 mils (0.015 mm) to 0.8 mils (0.020 mm). The primer coat was allowed to air dry one hour at room temperature before applying the topcoat finish.

The standard Navy urethane topcoat finish was prepared for spray application as specified in military specification MIL-C-81773B. Following an induction

period of 30 minutes, a mist coat of the prepared urethane topcoat was spray applied to the epoxy primed test panels. Following an air-dry period of 30 minutes, a second full hiding coat was applied to obtain a total dry film thickness of 2.6 mils (0.066 mm) to 3.0 mils (0.076 mm).

The NRL pigmented and clear topcoat finishes were prepared by adding 2 ounces (56.70 gms) of Component II to 4 ounces (113.40 gms) of Component I. After thoroughly mixing Components I and II, 1 ounce (28.35 gms) of Component III was added to the resin/isocyanate solution and mixed thoroughly. An induction period of 30 minutes was allowed before the coatings were spray applied to the epoxy primed test panels, utilizing the same procedure described for the MIL-C-81773B topcoat.

The clear NRL fluorinated coating was applied as a one coat protective finish to test panels painted with the MIL-C-81773B (urethane), MIL-C-22750B (epoxy) and MIL-L-81352A (acrylic) topcoats. These tests were conducted to study the gloss retention, flexibility, weathering and soil resistant properties of topcoated test panels overcoated with the NRL clear in comparison with topcoated test panels that were not overcoated with the NRL clear.

Since being superseded by the more durable MIL-C-81773B linear urethane topcoats, the use of the epoxy polyamide topcoats has been limited, being utilized occasionally by the Fleet for minor touch-up and overspray.

Specification MIL-L-81352A coating, a one component acrylic based topcoat, is also utilized by the Fleet for touch-up work. The coating is also being applied, on a limited basis, to naval training aircraft.

CONDITIONING OF COATINGS

The test panels coated with the epoxy primer and selected topcoats were allowed to cure at room temperature for 7 days before the chemical and physical tests were performed.

The MIL-C-81773B urethane topcoated panels, as well as the MIL-C-22750B epoxy and MIL-L-81352A acrylic topcoated test panels, were also allowed to air dry 7 days before and after the clear NRL fluorinated protective overcoat was applied. The purpose of the 7-day waiting period was to obtain realistic intercoat adhesion data, as topcoats applied to aged coatings sometimes do not adhere properly, resulting in intercoat adhesion problems. If the NRL clear coating is selected for use as a protective film on painted exterior aircraft surfaces, it must adhere to aged exterior topcoats to be effectively applied at the Fleet level of maintenance.

TEST DATA

ADHESION

The NRL pigmented topcoats (gray and white), as well as the NRL clear coating, exhibited excellent wet adhesion and water resistant properties and satisfactorily met the anchorage tape test requirements for linear urethane coatings specified in paragraph 4.6.6 of military specification MIL-C-81773B. The NRL coatings were also comparable to the MIL-C-81773B topcoats when subjected to the coating knife test outlined in Federal Test Method Standard No. 141A, Method 6304.1.

WORK LIFE

The NRL gray and white pigmented topcoats, when thinned using cellosolve acetate solvent to a viscosity of 16 seconds using a No. 4 Ford Cup, and allowed to stand in a closed vessel for 4 hours, increased to a viscosity of 18 to 19 seconds. The NRL pigmented coatings, therefore, meet the 25 percent allowable increase in viscosity when tested in accordance with paragraph 4.6.2 of military specification MIL-C-81773B.

The NRL clear coating exceeded the pot life requirements of paragraph 4.6.2 as the initial viscosity (no thinning required) increased to 26 seconds after the 4-hour ageing period. Although the clear coating exceeded the 25 percent allowable increase in viscosity, the coating remained clear and could easily be spray applied upon readjusting the viscosity to 18 seconds (No. 4 Ford Cup) using urethane grade cellosolve acetate thinner.

HEAT RESISTANCE

The resistance to heat test, conducted in accordance with paragraph 4.6.13 of specification MIL-C-81773B, consisted of subjecting the NRL gloss white topcoat to temperatures of 260 $\pm$ 5°F (126 $\pm$ 3°C) for 20 hours, followed by a temperature of 325 $\pm$ 5°F (162 $\pm$ 3°C) for one hour. Following the heating cycle, this coating exhibited a "B" reflectance value of 85.4, well within the 80 minimum value requirement specified in paragraph 3.10.4 of specification MIL-C-81773B.

An accelerated heat resistance test was also conducted to evaluate the high temperature properties of the NRL fluorinated coating compared with the MIL-C-81773B urethane, MIL-C-22750B epoxy and MIL-L-81352A acrylic topcoats. The painted test panels, all of which were epoxy primed, were subjected to a temperature of 350 $\pm$ 5°F (176 $\pm$ 3°C) in a circulating oven for one hour. The test panels were then removed, allowed to cool to room temperature and examined. A second set of test panels was tested under the same conditions, except the oven temperature was increased to 400 $\pm$ 5°F (204 $\pm$ 3°C).

Presented in Table I are the 60 degree gloss and blue filter reflectance values taken before and after the designated heating test periods. The

TABLE I

HEAT RESISTANCE TEST DATA

Applied Topcoat	INITIAL 60° Gloss	INITIAL Reflectance Blue Filter	(350°F)(178°C) - 1 HOUR 60° Gloss	(350°F)(178°C) - 1 HOUR Reflectance Blue Filter	(350°F)(178°C) - 1 HOUR Condition of Coating	(400°F)(204°C) - 1 HOUR 60° Gloss	(400°F)(204°C) - 1 HOUR Reflectance Blue Filter	(400°F)(204°C) - 1 HOUR Condition of Coating
NRL White	72.7	88.40	47.4	81.18 (S) (VS)	N.F.	38.8	56.67(D)(3)	N.F.
MIL-C-81773B White	93.4	90.38	89.1	81.68(S)(VS)	N.F.	85.4	60.2(D)(2)	N.F.
MIL-L-81352B White	70.4	87.02	81.6	82.30	N.F.	84.6	73.76(D)(1)	N.F.
MIL-C-22750B White	95.5	87.87	75.1	45.28(D)	N.F.	50.9	26.20(D)(4)	N.F.

CODES: N.F. - No coating failure
(D) - Discolored
(S) - Stained
(VS) - Very slight
(1)(2)(3)(4) - Denotes severity of discoloration (1) least to (4) greatest

ALL TEST PANELS PRIMED WITH 1-COAT MIL-P-23377C PRIMER

60 degree gloss values show that after the 350°F (170°C) test period, the NRL white coating exhibits a dramatic loss in gloss, whereas the white MIL-C-81773B urethane coating shows only a slight loss in gloss. The MIL-C-22750B epoxy white coating, heated at the same temperature for the same period of time, dropped moderately in percent gloss, but discolored badly to a tan-brown color, losing its aesthetic value as a white coating. Characteristic of coatings based on methyl methacrylate resins, the MIL-L-81352A acrylic white coating increased in gloss and showed no change in color.

The 400°F (204°C) test illustrates the poor gloss retention of the NRL white coating and the epoxy MIL-C-22750B coating, whereas the acrylic MIL-L-81352A coating increases to a value comparable to the urethane MIL-C-81773B white topcoat. The epoxy MIL-C-22750B, as expected, exhibits the poorest reflectance value and the greatest discoloration. The MIL-L-81352A coating shows the best reflectance value, followed by the urethane (MIL-C-81773B), and the NRL white topcoats.

OIL RESISTANCE

The resistance of the topcoats to engine lubricating oil was tested according to paragraph 4.6.10 of military specification MIL-C-81773B. The painted panels were immersed in MIL-L-23699 lubricating oil at a temperature of 250 ± 4°F (121 ± 4°C) for a period of 4 hours. Four hours after removal from the hot oil, the panels were examined for blistering, film softening, discoloration and other film defects.

Additional chemical resistance tests were conducted on painted test panels immersed in hot MIL-H-5606, MIL-H-83282H and Skydrol 500B hydraulic oils. The tests were conducted under the same conditions as specified for the MIL-L-23699 lubricating oil. Specification MIL-H-5606 is the standard hydraulic oil currently utilized on naval aircraft. Specification MIL-H-83282H oil, a higher temperature performing oil, is programmed to supersede MIL-H-5606 hydraulic oil. Skydrol 500B, a proprietary hydraulic oil, was also included in the test to obtain data on the alkyl phosphate ester based hydraulic oil currently being utilized on most commercial aircraft and selected naval aircraft.

The coatings and oils selected for the hot oil resistance tests, and their chemical resistant properties are illustrated in Table II.

$NaCl$-SO_2 EXPOSURE

Because carrier based aircraft are exposed to operational environments that include heavy corrosive salt spray, engine exhaust and carrier stack gases, extensive coating tests were conducted by exposing painted test panels to the $NaCl$-SO_2 exposure chamber. Three separate exposure tests were selected to obtain comprehensive data.

TABLE II

HOT OIL RESISTANCE TEST DATA

Applied Topcoat	Clear Overcoat	MIL-L-23699 OIL	MIL-H-5606 OIL	MIL-H-83282H OIL	SKYDROL 500B
NRL Clear		P (NFD)	P (NFD)	P (NFD)	F
NRL White		P (NFD)	P (NFD)	P (NFD)	F
NRL Gray		P (NFD)	P (NFD)	P (NFD)	F
MIL-C-81773B White		P (NFD)	P (NFD) (ST) (VS)	P (NFD) (ST) (VS)	F
MIL-C-81773B White	NRL	P (NFD)	P (NFD) (ST) (VS)	P (NFD) (ST) (VS)	F
MIL-C-81773B Gray		P (NFD)	P (NFD)	P (NFD)	F
MIL-C-81773B Gray	NRL	P (NFD)	P (NFD)	P (NFD)	F
MIL-L-81352A White		P (NFD)	P (NFD)	P (NFD) (ST) (VS)	F
MIL-L-81352A White	NRL	P (NFD)	P (NFD) (ST) (VS)	P (NFD) (ST) (VS)	F
MIL-L-81352A Gray		P (NFD)	P (NFD)	P (NFD)	F
MIL-L-81352A Gray	NRL	P (NFD)	P (NFD)	P (NFD) (ST) (VS)	F
MIL-C-22750B White		F (B) (DS)	P (NFD) (DS)	P (NFD) (DS)	F
MIL-C-22750B White	NRL	P (NFD) (ST) (VS)	P (NFD)	P (NFD) (ST) (VS)	F
MIL-C-22750B Gray		P (NFD)	P (NFD)	P (NFD)	F
MIL-C-22750B Gray	NRL	P (NFD)	P (NFD)	P (NFD)	F

CODES:
- P - Pass
- F(B) Fail (blisters)
- NFD - No film defects
- VS - Very slight
- ST - Stained
- DS - Discoloration

Test No. 1

Test panels consisting of 2024 and 7075 (bare and clad) aluminum alloy measuring 3 x 6 x 0.020 in. (7.62 x 15.24 x 0.51 cm) were selected as the substrate alloys. The test panels were divided in 16 groups, each group consisting of two test panels.

Prior to applying the primer and topcoat finishes, an "X" pattern was applied to each panel using 1/8 in. wide pressure sensitive vinyl tape. The primer and topcoats were then applied as described in Tables III and IV and allowed to air dry overnight. The following day, the masking tape was carefully removed, leaving a clean, unpainted "X" pattern. After air drying seven days, the edges of the painted test panels, prior to subjecting them to the NaCl-SO_2 chamber, were coated with beeswax to prevent premature edge failures.

The panels were exposed to the NaCl-SO_2 test chamber for an 800-hour period, and were examined at the end of each consecutive 100-hour period. Upon completion of the 800-hour exposure, the panels were rinsed with distilled water until neutral to litmus paper, dried and subjected to the cross-hatched tape adhesion test. The test was performed one hour after removal of the panels from the NaCl-SO_2 chamber by scribing to the base metal to produce a 1/4 in. squared pattern. Pressure sensitive masking tape (3M 250) was pressed firmly to the scribed pattern and removed in one quick motion. The panels were then examined for intercoat or primer to substrate adhesion failures.

The technique of masking off an "X" pattern prior to painting the panels and, in addition, performing the metal scribe test for adhesion after completing the NaCl-SO_2 test, was selected for two reasons:

1. To mechanically scribe pretreated and painted test panels to a uniform depth is difficult and, therefore, the depth of penetration from panel to panel varies, resulting in a ragged and rough surface cut. Subsequently, corrosion occurring at the scribe mark can vary in severity and may not be entirely indicative of the protective properties of the applied metal pretreatment and organic protective paint coating.

2. Mechanically scribing of painted test panels severely damages the base metal and the damage imposed is not indicative of the type of surface defects found on painted exterior skins of naval aircraft.

Most corrosion problems associated with exterior aircraft surfaces and/or structures occur around fasteners, butt joints, access doors, etc., where penetration of paint is poor and voids exist, and where dynamic loads are high enough to cause "working" and subsequent cracking of the paint film. Other minor defects are attributed to poor surface preparation and paint application procedures leading to primer or primer to topcoat adhesion failures. By utilizing the masked off "X" mark, a more clearly defined protective measure of the applied primer and topcoat finishes can be achieved

TABLE III

DESCRIPTION OF NaCl-SO_2 TEST PANELS

2024 ALUMINUM ALLOYS

Figure No.	Group No.	Metal Finish	Chemical Pretreatment	Primer Coat	Topcoat Finish
1	1A 1B	Bare aluminum	MIL-C-5541B, Class 1A	MIL-P-23377C	MIL-C-81773 NRL Gray
2	2A 2B	Clad aluminum	MIL-C-5541B, Class 1A	MIL-P-23377C	MIL-C-81773 NRL Gray
3	3A 3B	Bare aluminum	MIL-A-8625C, Type II	MIL-P-23377C	MIL-C-81773 NRL Gray
4	4A 4B	Clad aluminum	MIL-A-8625C, Type II	MIL-P-23377C	MIL-C-81773 NRL Gray
5	5A 5B	Bare aluminum	MIL-A-8625C, Type I	MIL-P-23377C	MIL-C-81773 NRL Gray
6	6A 6B	Clad aluminum	MIL-A-8625C, Type I	MIL-P-23377C	MIL-C-81773 NRL Gray
7	7A 7B	Bare aluminum	MIL-A-8625C, Type II Class 1	MIL-P-23377C	MIL-C-81773 NRL Gray
8	8A 8B	Clad aluminum	MIL-A-8625C, Type II Class 1	MIL-P-23377C	MIL-C-81773 NRL Gray

TABLE IV

DESCRIPTION OF $NaCl-SO_2$ TEST PANELS

7075 ALUMINUM ALLOYS

Figure No.	Group No.	Metal Finish	Chemical Pretreatment	Primer Coat	Topcoat Finish
9	9A 9B	Bare aluminum	MIL-C-5541B, Class 1A	MIL-P-23377C	MIL-C-81773 NRL Gray
10	10A 10B	Clad aluminum	MIL-C-5541B, Class 1A	MIL-P-23377C	MIL-C-81773 NRL Gray
11	11A 11B	Bare aluminum	MIL-A-8625C, Type II	MIL-P-23377C	MIL-C-81773 NRL Gray
12	12A 12B	Clad aluminum	MIL-A-8625C, Type II	MIL-P-23377C	MIL-C-81773 NRL Gray
13	13A 13B	Bare aluminum	MIL-A-8625C, Type I	MIL-P-23377C	MIL-C-81773 NRL Gray
14	14A 14B	Clad aluminum	MIL-A-8625C, Type I	MIL-P-23377C	MIL-C-81773 NRL Gray
15	15A 15B	Bare aluminum	MIL-A-8625C, Type II Class 1	MIL-P-23377C	MIL-C-81773 NRL Gray
16	16A 16B	Clad aluminum	MIL-A-8625C,Type II Class 1	MIL-P-23377C	MIL-C-81773 NRL Gray

in conjunction with the behavior of the substrate metal to which the finishes are applied.

The test method used for the NaCl-SO_2 test study was selected to provide coating data related to two aspects. The first relates to the protective qualities of the applied coatings which include a corrosion inhibitive primer and the applied topcoat under study. The protective properties of the coating as a continuous and discontinuous film, at the masked off "X", provided data related to the adherent qualities of the paint coatings when the base metal/primer-topcoat interface is exposed to moisture, SO_2 gases, salt fog, etc. Marginally adhered coatings generally fail (lift) from the substrate when attacked at the coating edge/substrate metal interface. This phenomenon occurs on many areas of exterior painted skins of aircraft, such as butt joints, edges of access doors, removable fasteners, worked rivets and damaged (scuffed) paint films.

The second aspect of the NaCl-SO_2 test relates to the overall effectiveness of the total system, which includes the selected substrate metal, the applied inorganic chemical conversion or anodic coating, and the final organic finish, which includes a corrosion inhibitive primer and topcoat finish.

Figures 1 through 16 illustrate the overall effectiveness of the MIL-C-81773B linear urethane coating compared to the NRL fluorinated epoxy-polyurethane coating. Both topcoats, after the 800 hour exposure period, displayed comparable corrosion resistance and intercoat (primer to topcoat) adhesion. No primer to substrate or topcoat to primer intercoat failures occurred, as evidenced by the cross hatch-tape test conducted on each test panel.

From an overall observation, it can be concluded that the linear MIL-C-81773B top finish was equal, or slightly superior, to the NRL fluorinated topcoat finish.

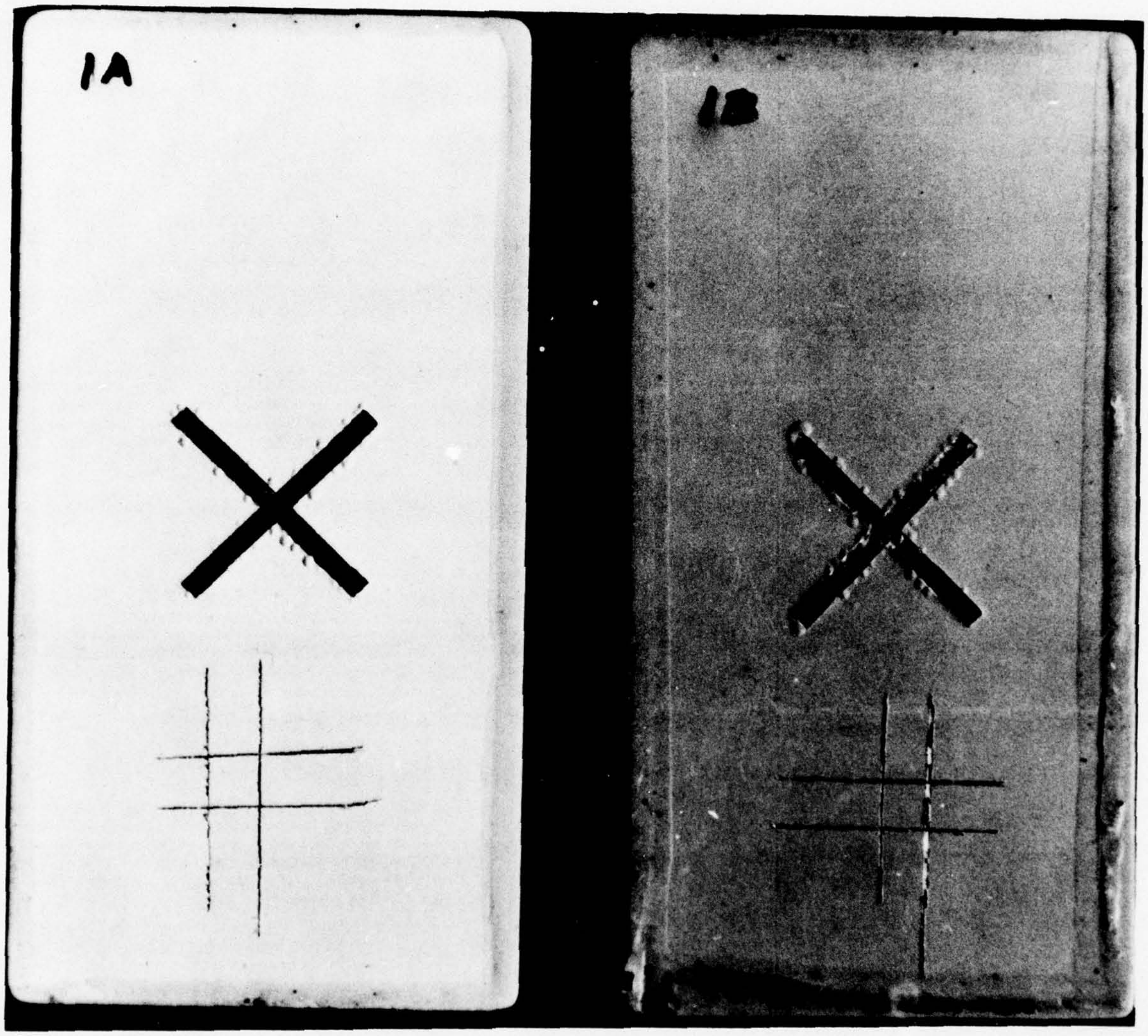
Table V illustrates the overall effectiveness of the total protective system. The applied primer and topcoat remain constant, the variation being based on the selected substrate alloy and applied pretreatment (chemical conversion, anodic, and/or both). Test panels identified as No. 1 and No. 2 exhibited the best overall corrosion protection, and test panels identified as Nos. 15 and 16 afforded the least corrosion protection.

Test No. 2

This test was selected to demonstrate the effectiveness of the topcoats when applied to aged and reworked aluminum substrates compared with topcoats applied to new aluminum substrates. The reworked substrates were selected to resemble the skin condition of an aircraft that has undergone more than one overhaul and rework cycle (strip-chemical treat-paint) at a naval rework facility. To obtain the aged panels, 5 x 16 x 0.020 in. (12.70 x 40.64 x 0.05 cm) 2024 clad aluminum panels, treated with a chemical conversion coating meeting MIL-C-5541, Class 1A treatment, were exposed (unpainted) for

SALT SPRAY AND SO_2 TEST

1A 1B



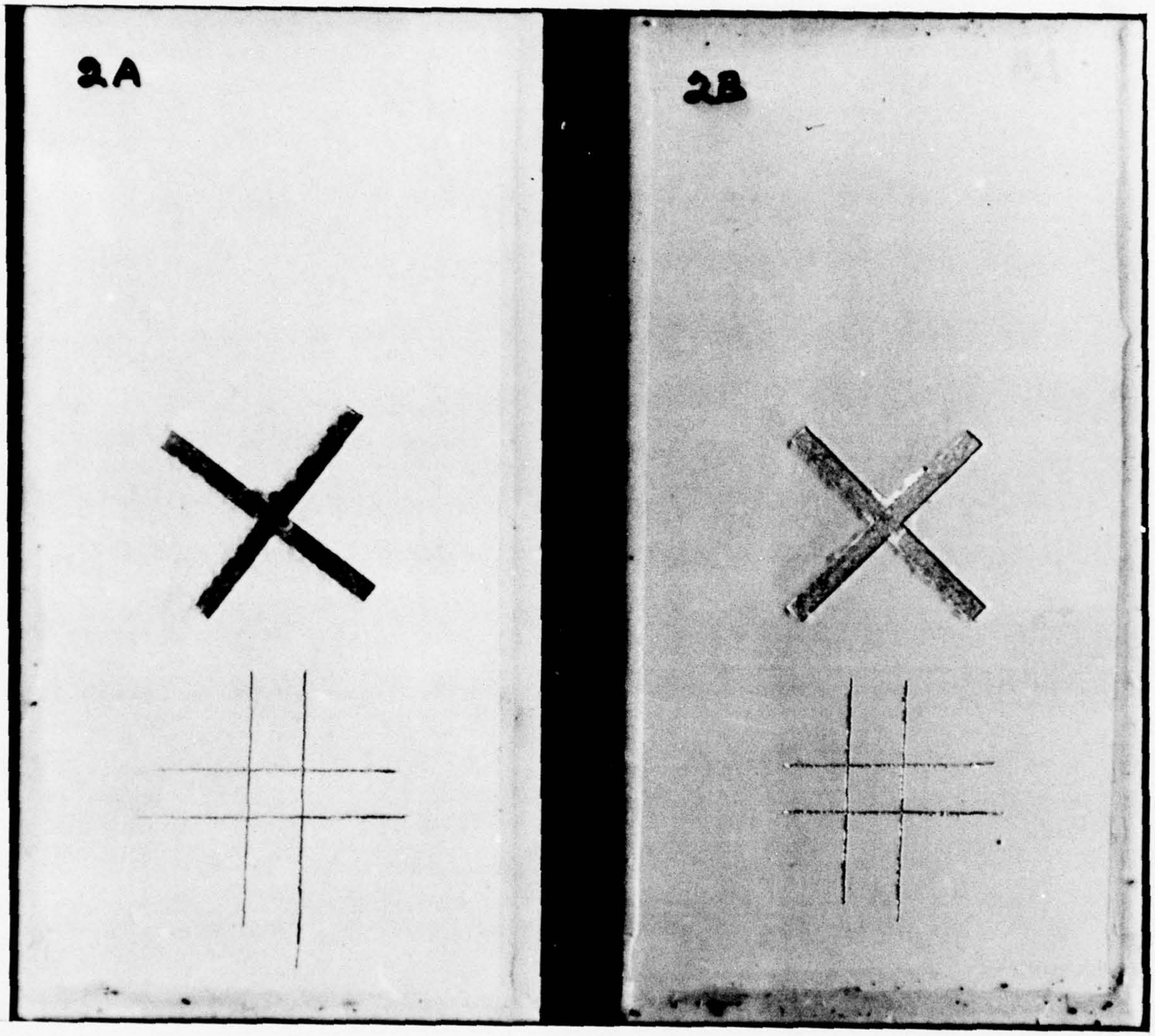
EPOXY PRIMER
URETHANE TOPCOAT

EPOXY PRIMER
NRL TOPCOAT

FIGURE 1

SALT SPRAY AND SO_2 TEST

2A 2B



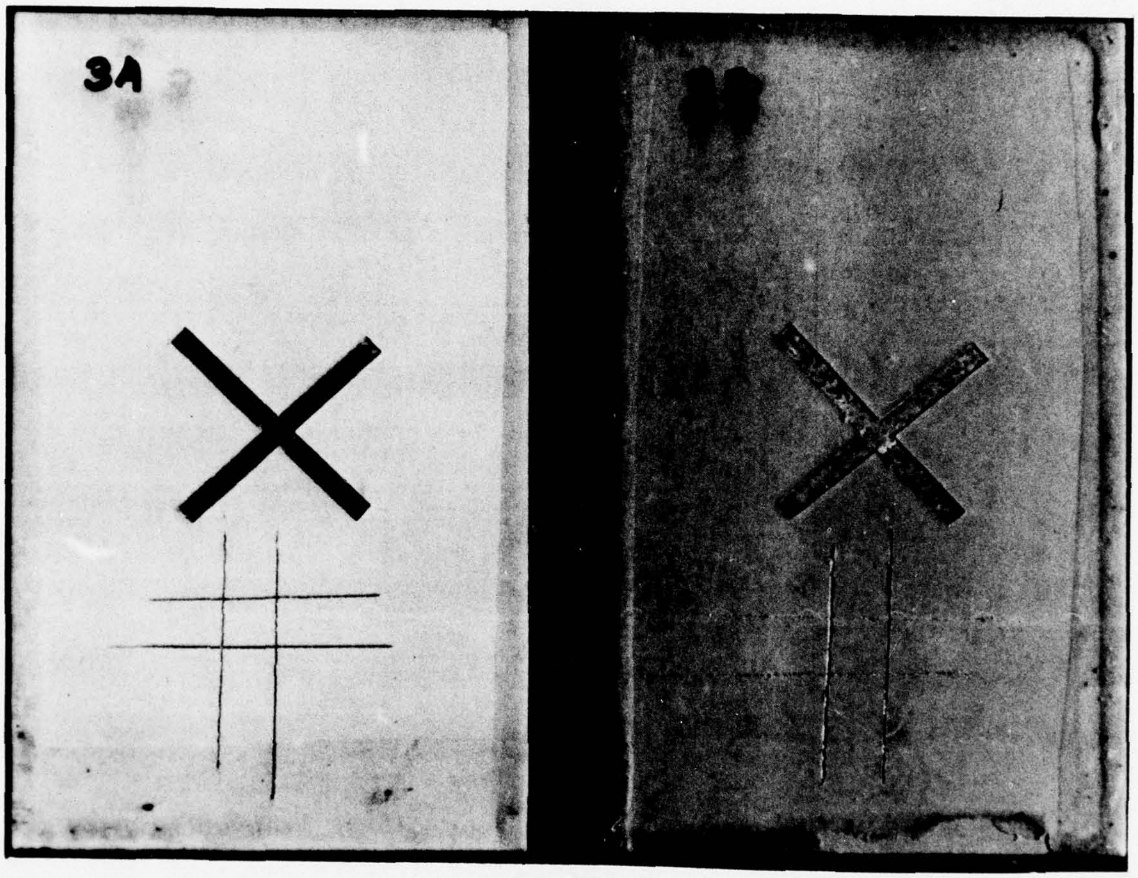
EPOXY PRIMER
URETHANE TOPCOAT

EPOXY PRIMER
NRL TOPCOAT

FIGURE 2

SALT SPRAY AND SO_2 TEST

3A 3B



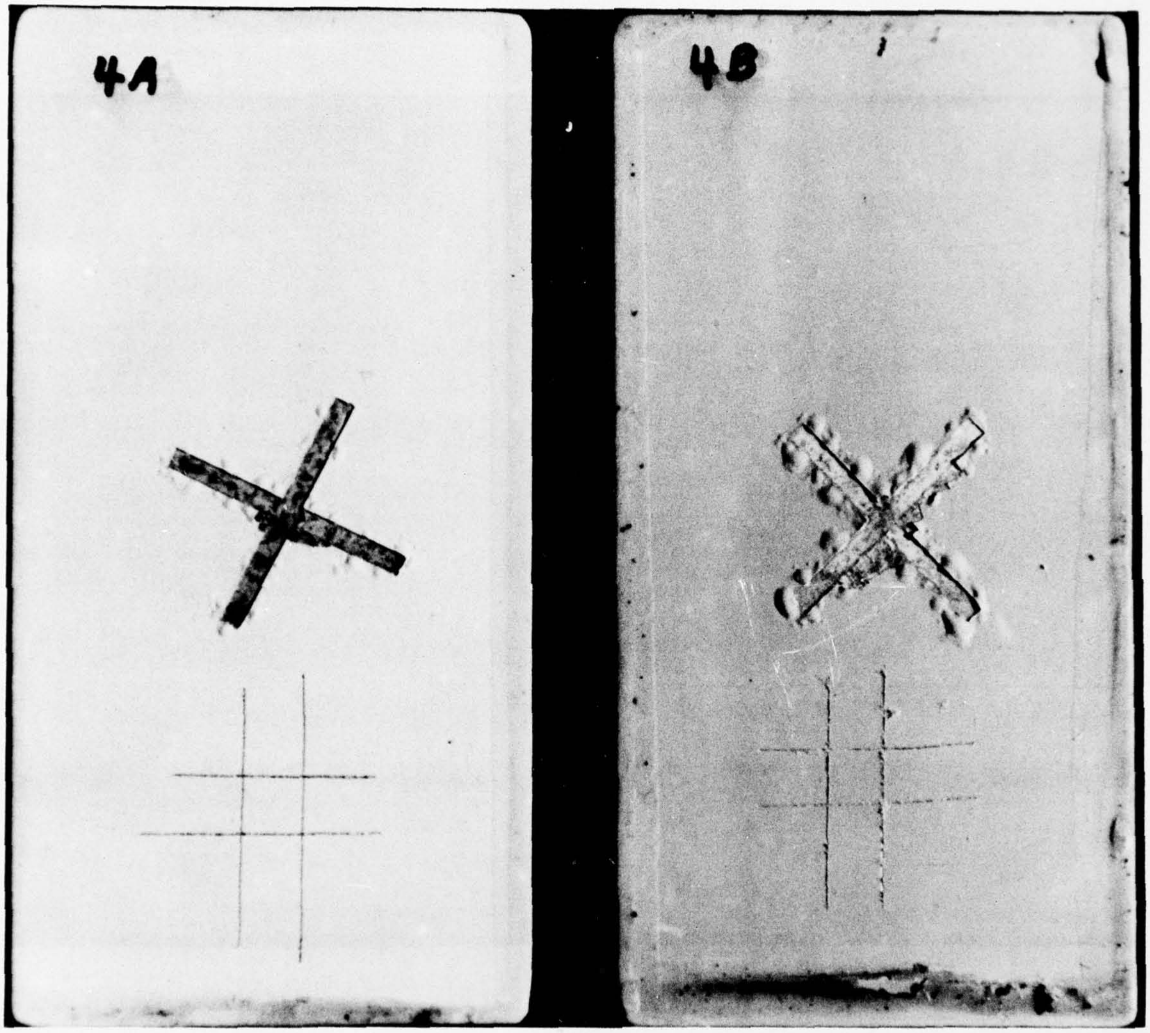
EPOXY PRIMER
URETHANE TOPCOAT

EPOXY PRIMER
NRL TOPCOAT

FIGURE 3

SALT SPRAY AND SO_2 TEST

4A 4B



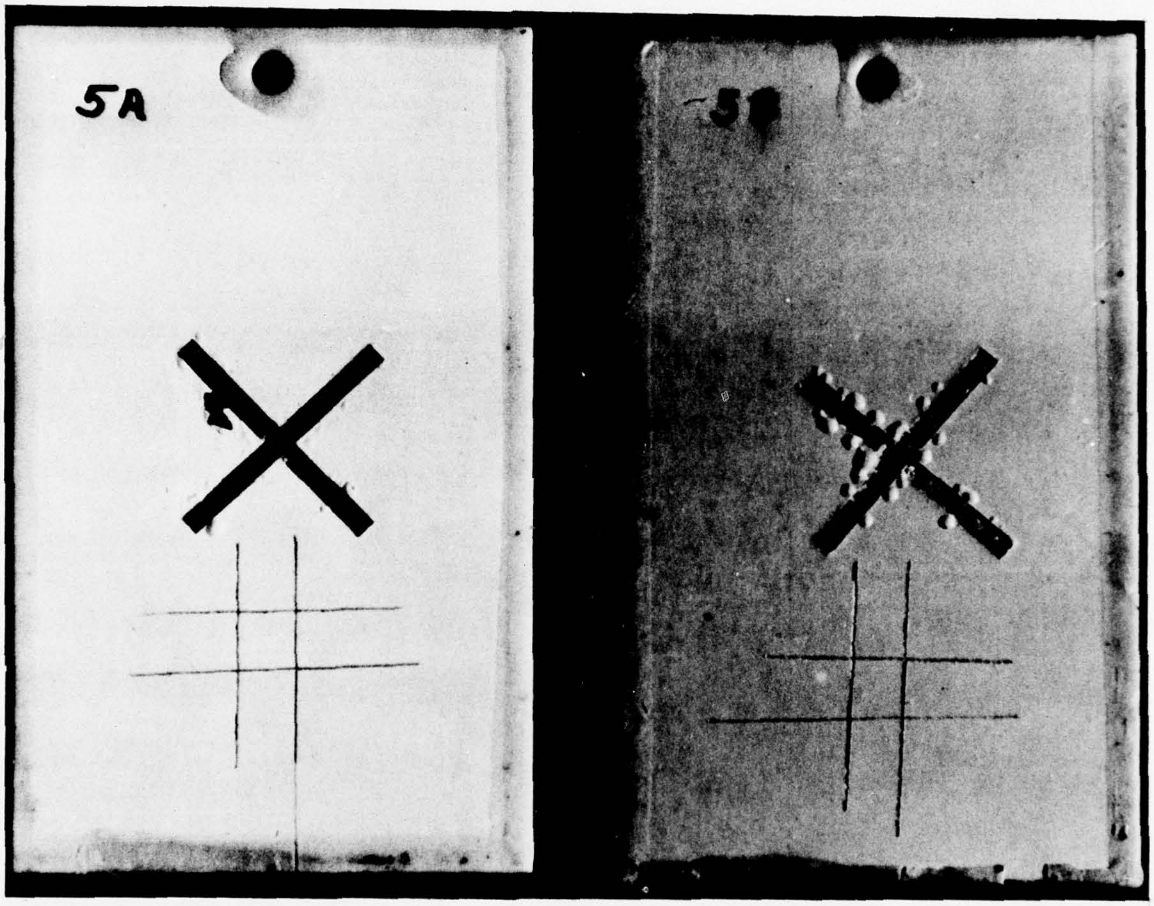
EPOXY PRIMER
URETHANE TOPCOAT

EPOXY PRIMER
NRL TOPCOAT

FIGURE 4

SALT SPRAY AND SO_2 TEST

5A 5B



EPOXY PRIMER
URETHANE TOPCOAT

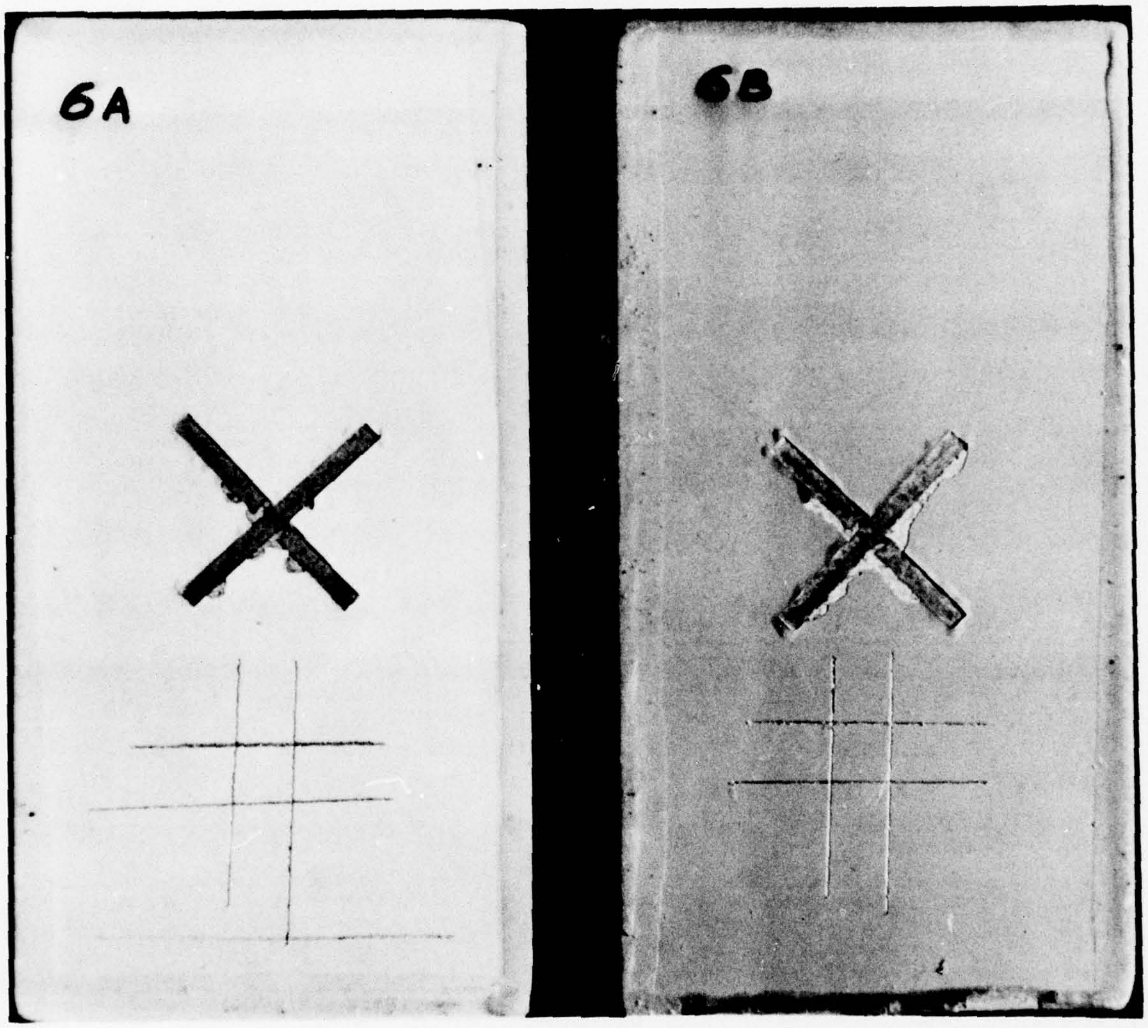
EPOXY PRIMER
NRL TOPCOAT

FIGURE 5

SALT SPRAY AND SO_2 TEST

6A

6B



EPOXY PRIMER

URETHANE TOPCOAT

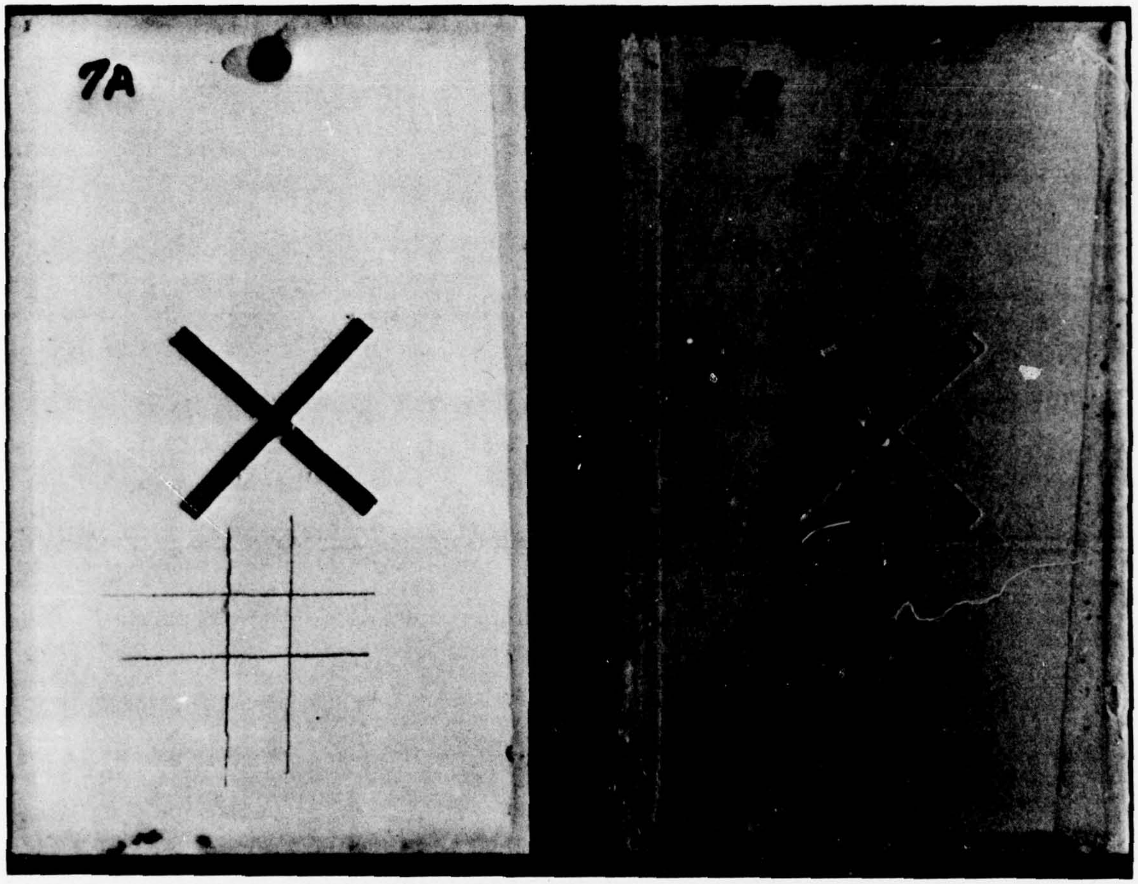
EPOXY PRIMER

NRL TOPCOAT

FIGURE 6

SALT SPRAY AND SO_2 TEST

7A 7B

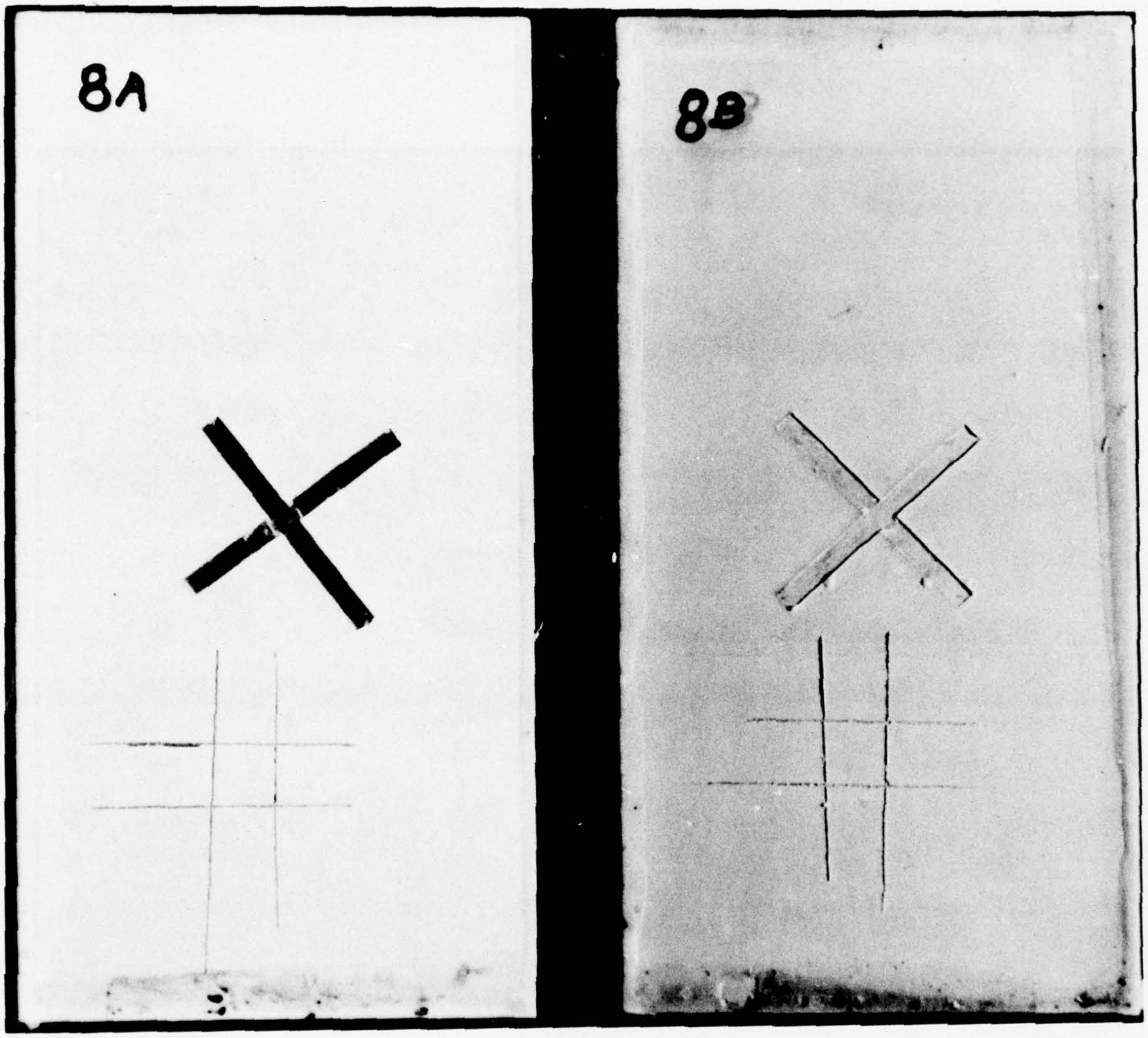


EPOXY PRIMER	EPOXY PRIMER
URETHANE TOPCOAT	NRL TOPCOAT

FIGURE 7

SALT SPRAY AND SO_2 TEST

8A　　　　　　　　8B



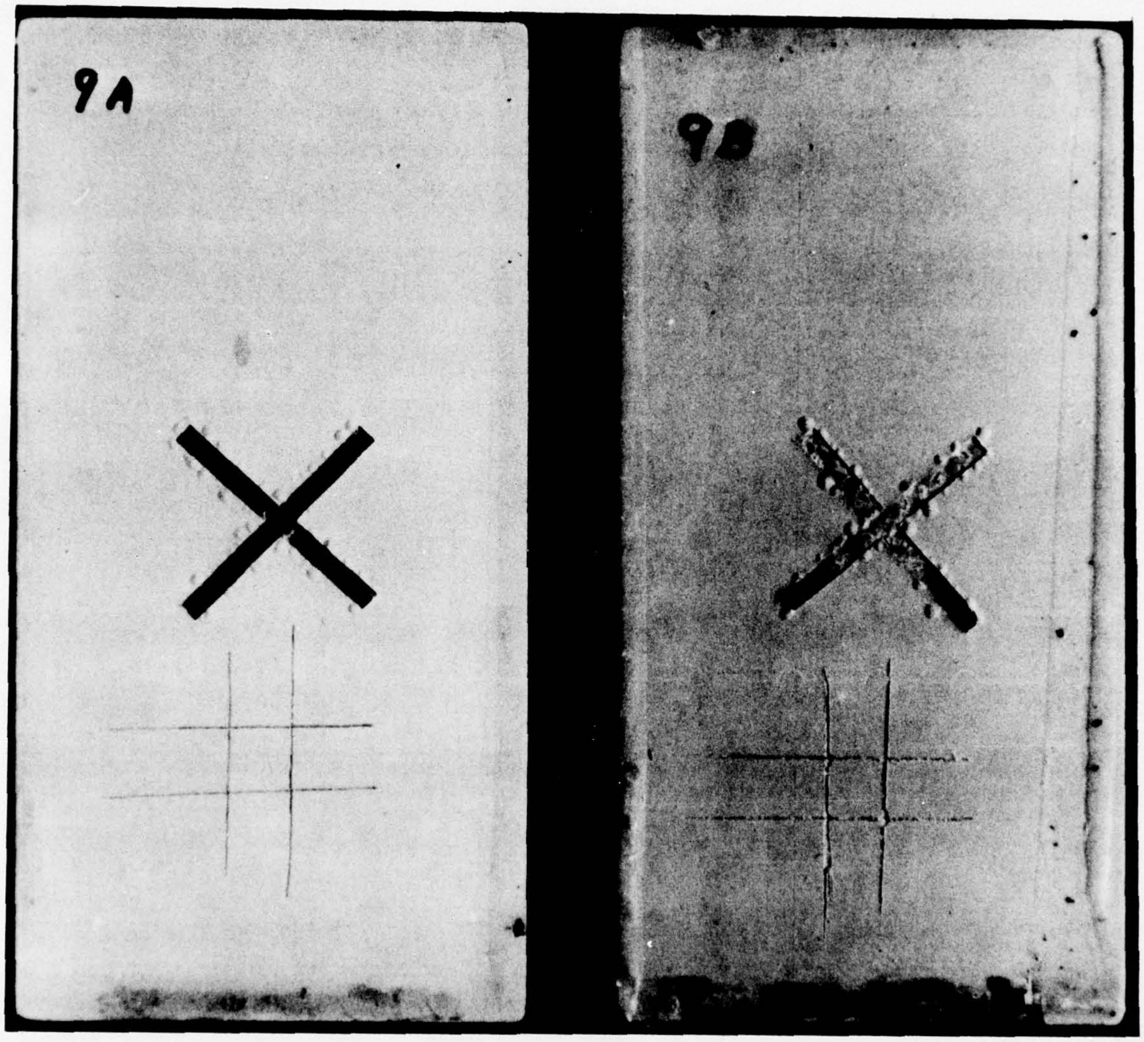
EPOXY PRIMER　　　　EPOXY PRIMER

URETHANE TOPCOAT　　　　NRL TOPCOAT

FIGURE 8

SALT SPRAY AND SO_2 TEST

9A 9B



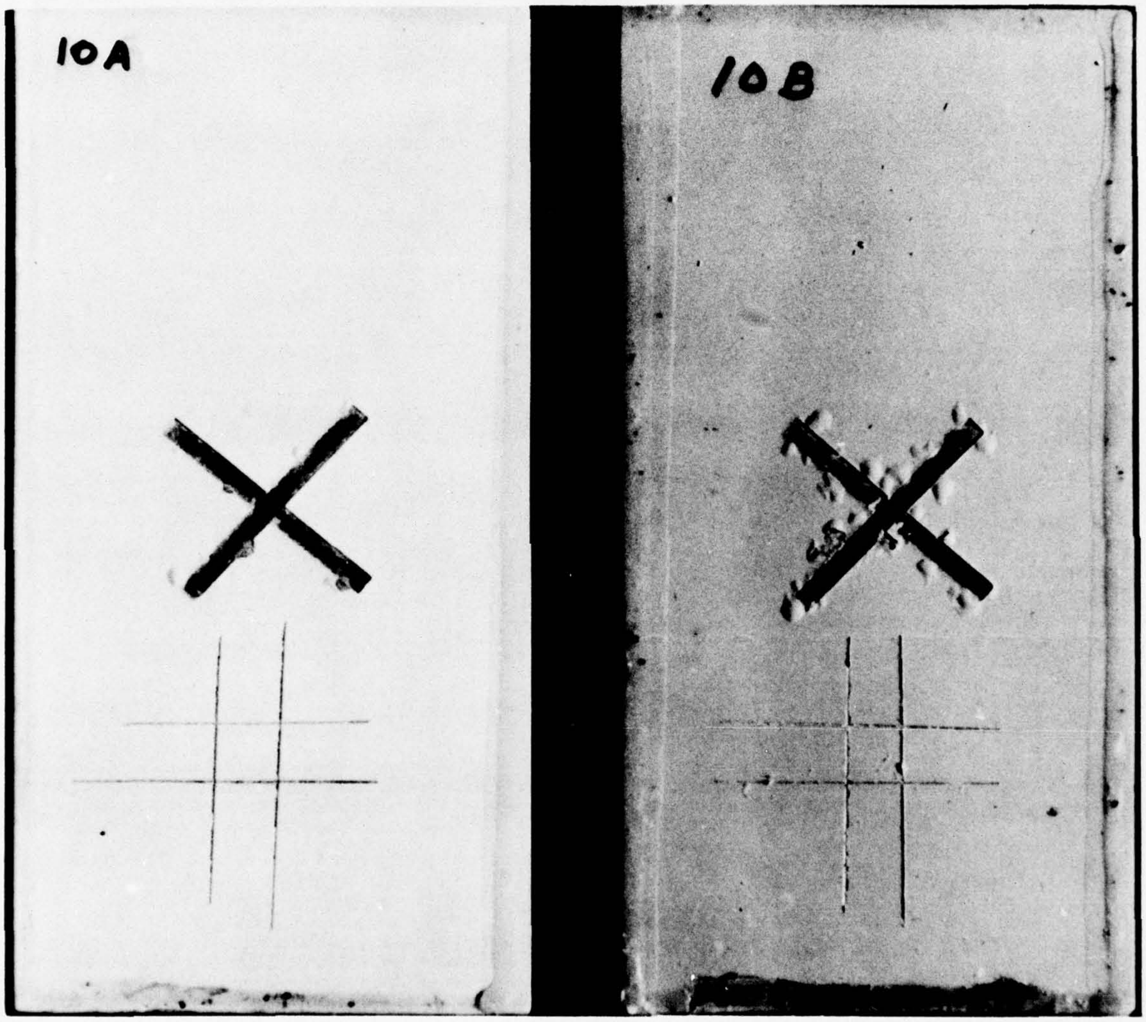
EPOXY PRIMER
URETHANE TOPCOAT

EPOXY PRIMER
NRL TOPCOAT

FIGURE 9

SALT SPRAY AND SO_2 TEST

10A 10B



EPOXY PRIMER
URETHANE TOPCOAT

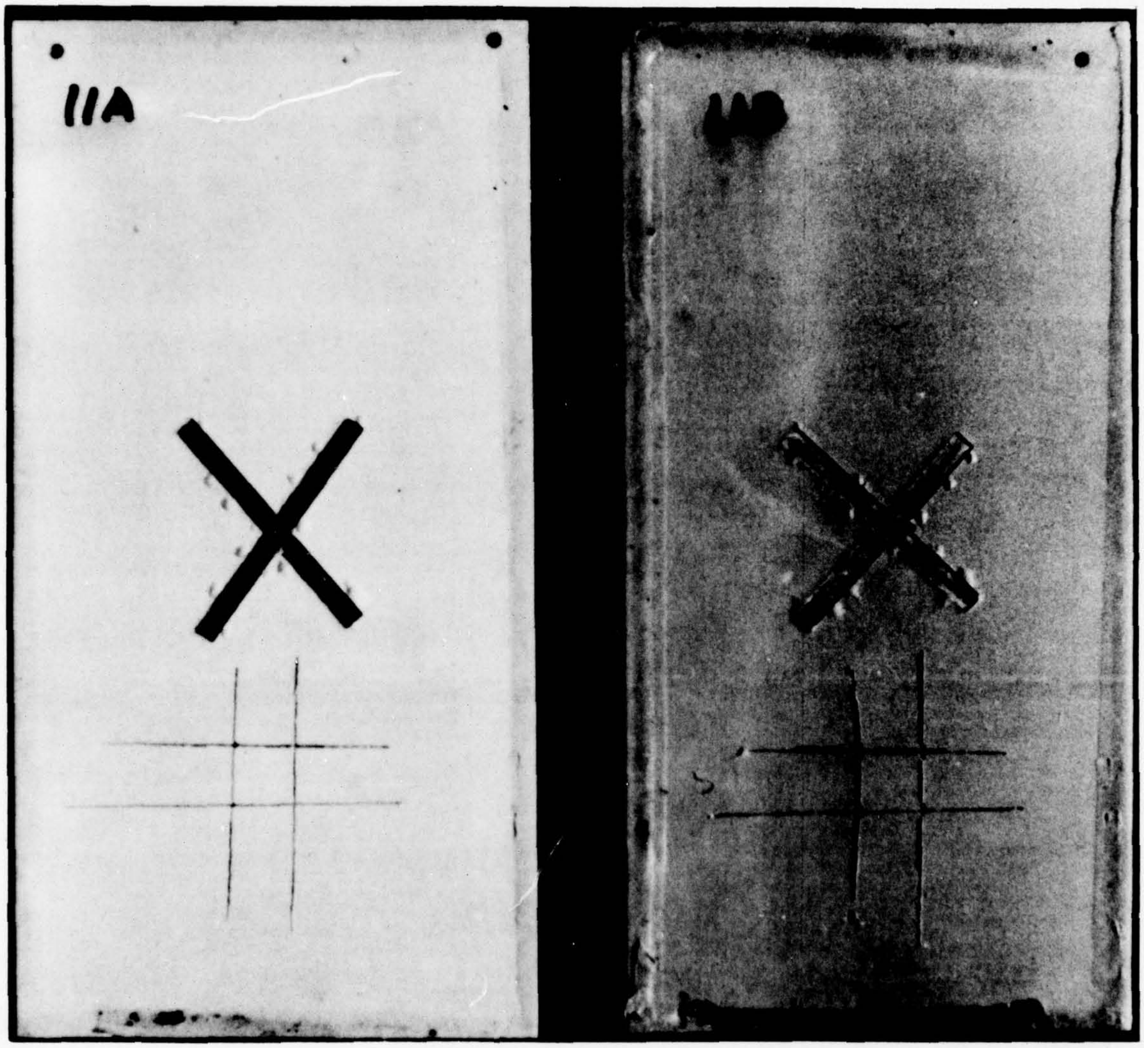
EPOXY PRIMER
NRL TOPCOAT

FIGURE 10

SALT SPRAY AND SO_2 TEST

11A

11B



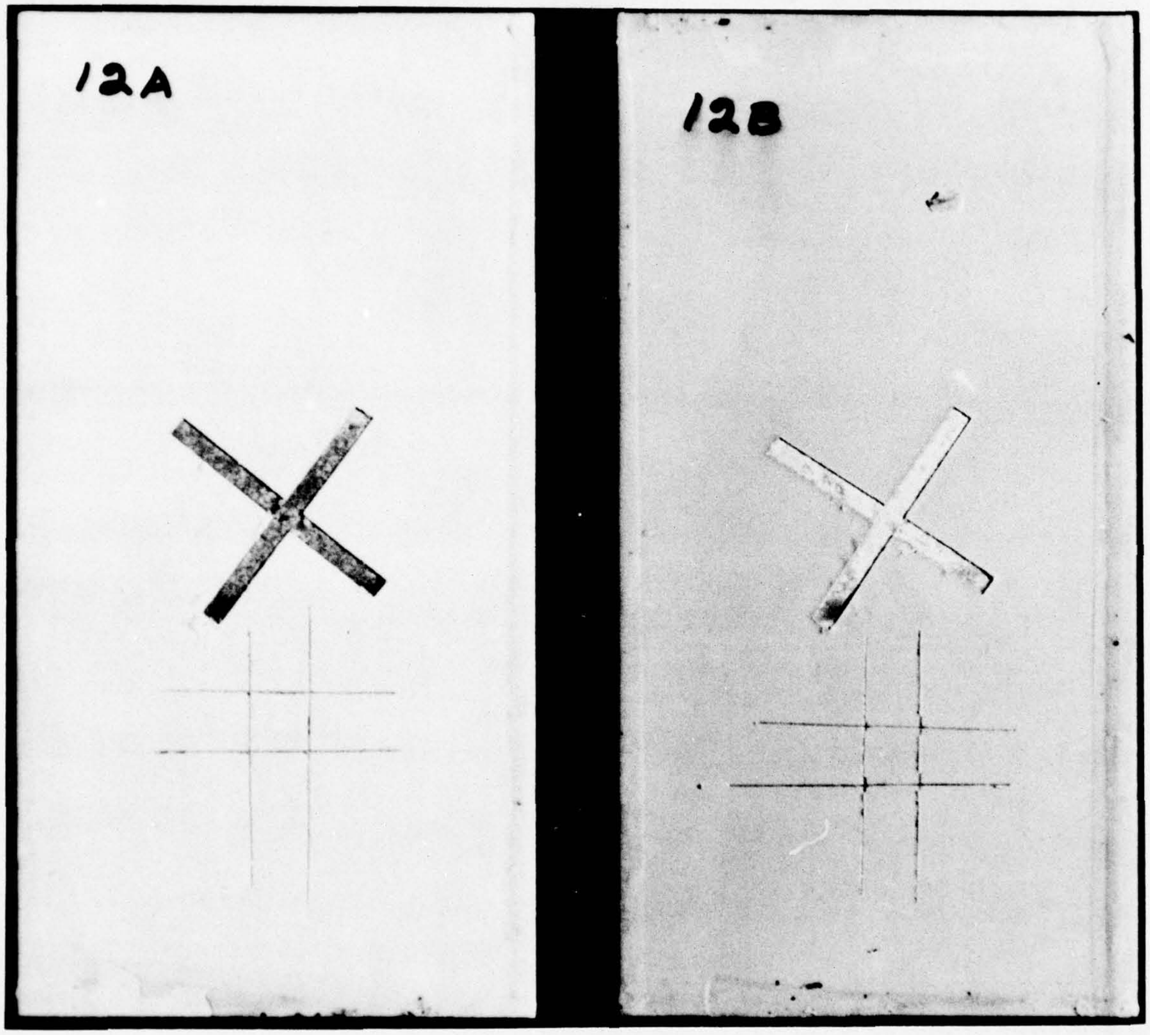
EPOXY PRIMER
URETHANE TOPCOAT

EPOXY PRIMER
NRL TOPCOAT

FIGURE 11

SALT SPRAY AND SO_2 TEST

12A 12B



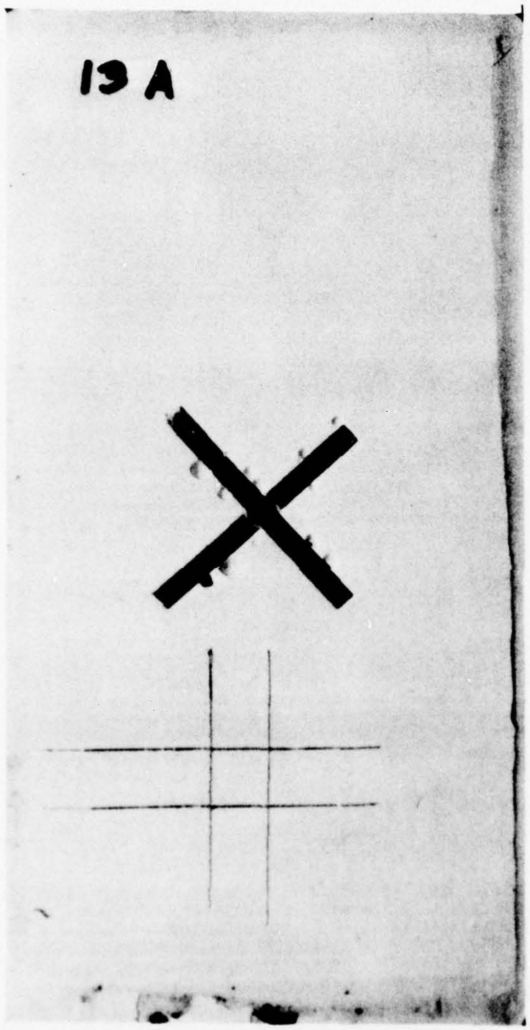
EPOXY PRIMER
URETHANE TOPCOAT

EPOXY PRIMER
NRL TOPCOAT

FIGURE 12

SALT SPRAY AND SO_2 TEST

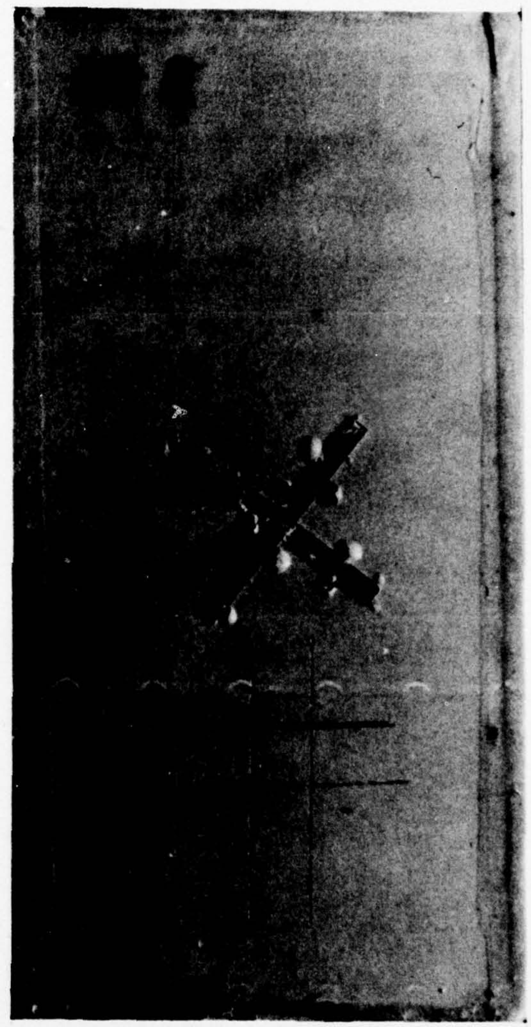
13A



EPOXY PRIMER

URETHANE TOPCOAT

13B



EPOXY PRIMER

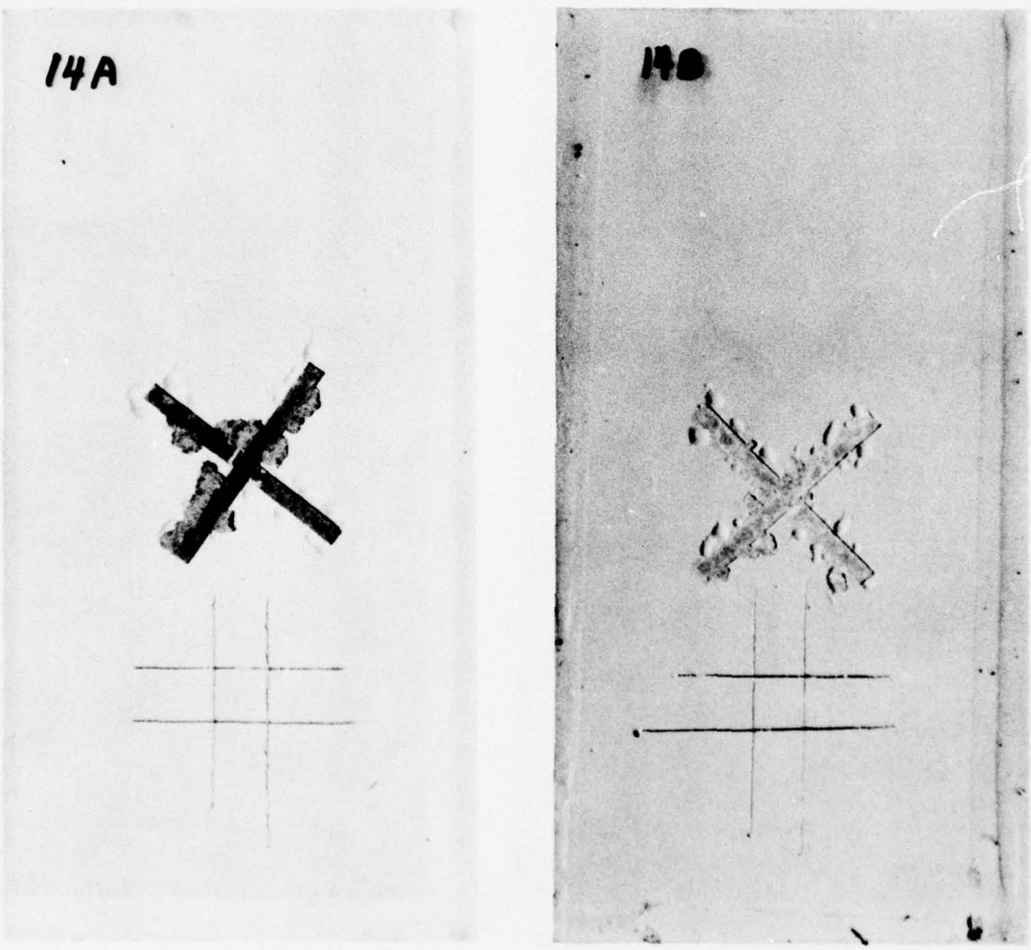
NRL TOPCOAT

FIGURE 13

SALT SPRAY AND SO_2 TEST

14A

14B



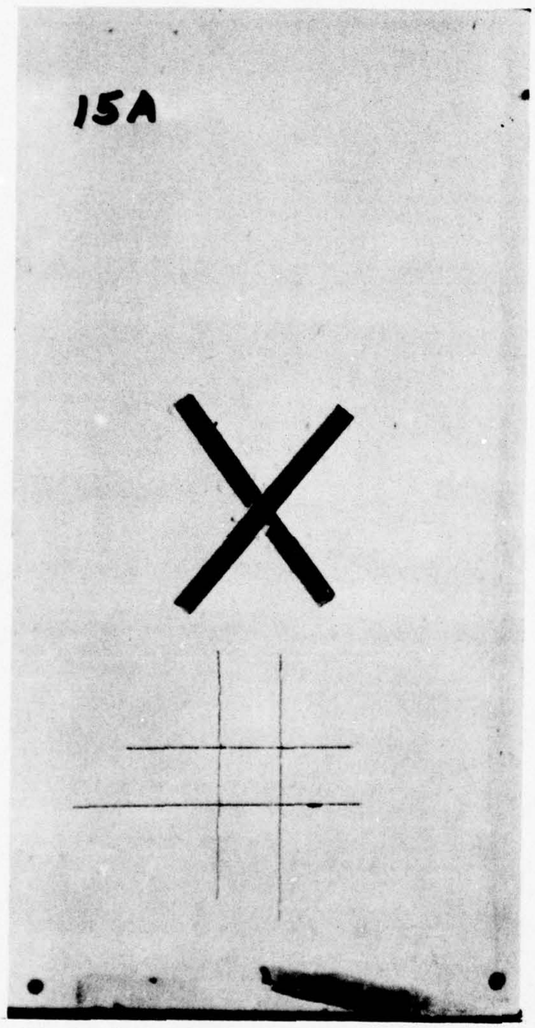
EPOXY PRIMER
URETHANE TOPCOAT

EPOXY PRIMER
NRL TOPCOAT

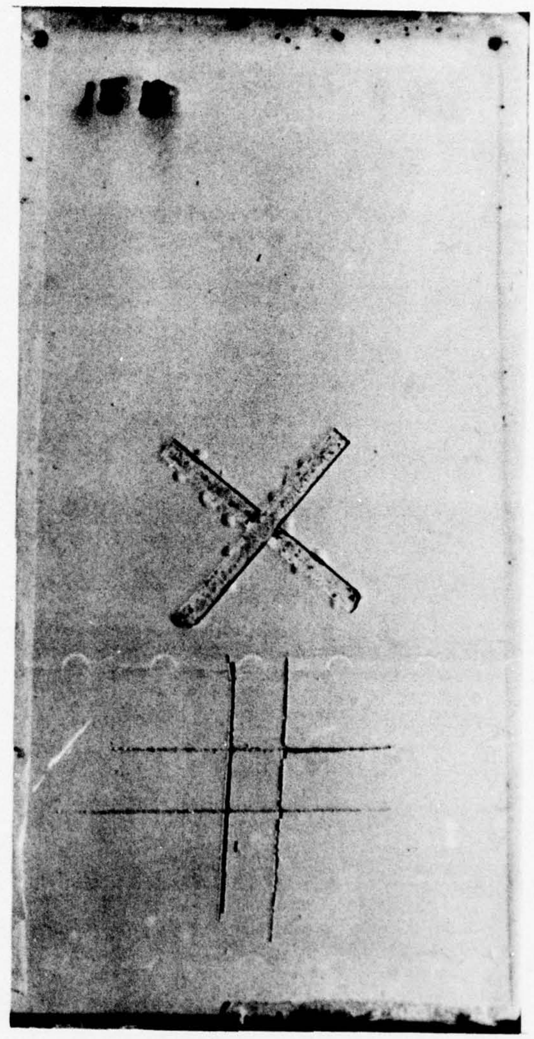
FIGURE 14

SALT SPRAY AND SO_2 TEST

15A



15B



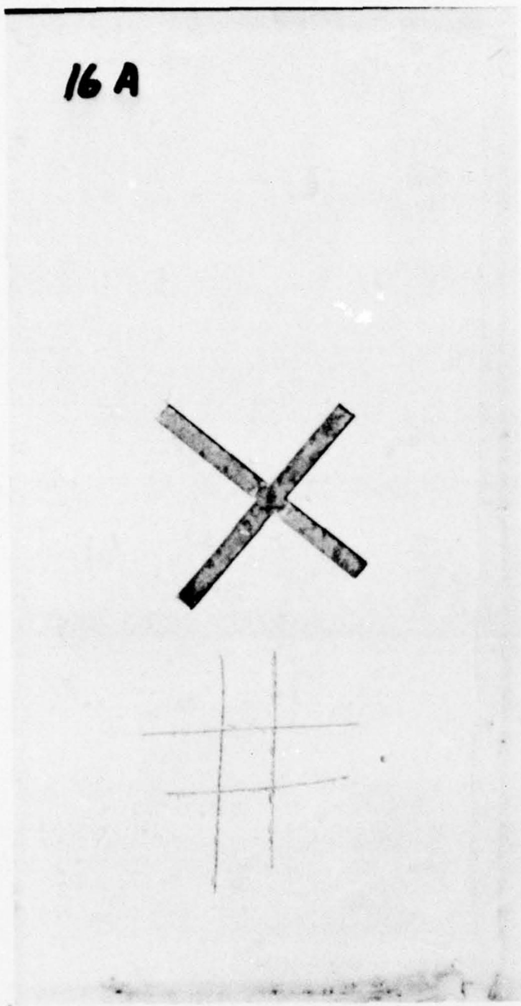
EPOXY PRIMER
URETHANE TOPCOAT

EPOXY PRIMER
NRL TOPCOAT

FIGURE 15

SALT SPRAY AND SO_2 TEST

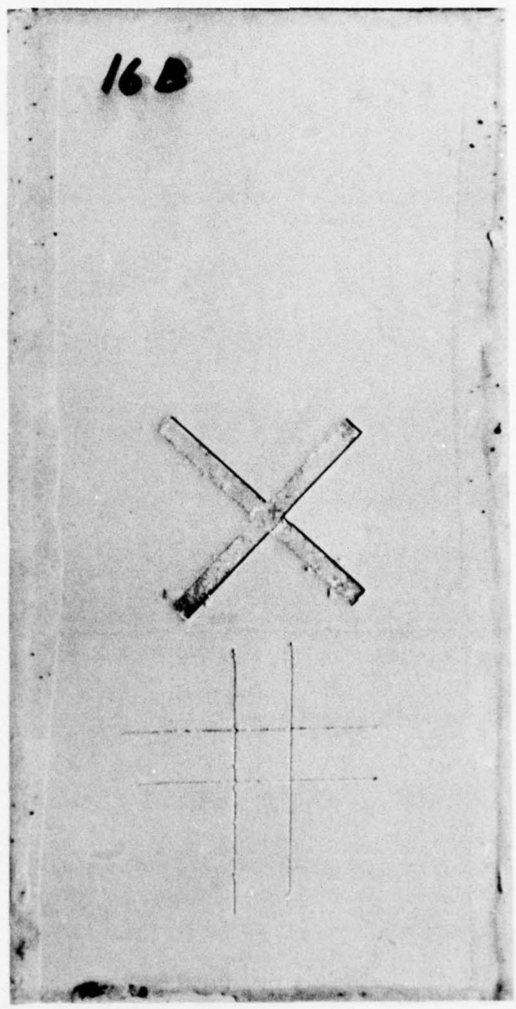
16A



EPOXY PRIMER

URETHANE TOPCOAT

16B



EPOXY PRIMER

NRL TOPCOAT

FIGURE 16

TABLE V

NaCl - SO_2 EXPOSURE TEST DATA

Designated Test Panel	CONDITION OF TEST PANELS — Exposure Periods in Hours: 300	500	800	Corrosion Rating Index	Aluminum Alloy * and Chemical Treatment
1 1A	No change	Sl. corrosion at X	Mod. corrosion at X Sm. paint blisters at X	10	2024B Iridite
1B	No change	Same as 1A	Same as 1A		
2 2A	No change	Sl. corrosion at X	Mod. corrosion at X Sm. paint blisters at X	7	2024C Iridite
2B	No change	Same as 2A	Same as 2A		
3 3A	No change	Sl. corrosion at X	Sl. to mod. corrosion at X	5	2024B Sulfuric Anodize
3B	No change	Same as 3A	Mod. corrosion at X V. Sm. paint blisters at X		
4 4A	No change	Sl. corrosion at X	Mod. pitting corrosion at X Sm. paint blisters at X	12	2024C Sulfuric Anodize
4B	No change	Sl. corrosion at X Sm. paint blisters at X	Ext. corrosion at X Paint failure at X		
5 5A	No change	Sl. corrosion at X V. Sm. paint blisters at X	Ext. pitting corrosion at X Lg. paint blisters at X	15	2024B Chromic Anodize
5B	V. Sm. paint blisters at X	Same as 5A	Same as 5A		
6 6A	No change	V. Sl. corrosion at X	Mod. corrosion at X Lg. paint blisters at X	13	2024C Chromic Anodize
6B	No change	Same as 6A	Ext. corrosion at X Paint lifting at X		
7 7A	No change	V. Sl. corrosion at X	Sl. corrosion at X	3	2024B Sulfuric Anodize Dichromate Seal
7B	No change	Same as 7A	Same as 7A		
8 8A	No change	No change	V.V. Sl. corrosion at X	1	2024C Sulfuric Anodize Dichromate Seal
8B	No change	No change	Same as 8A		
9 9A	No change	Sl. corrosion at X Sm. paint blisters at X	Mod. corrosion at X Sm. to Lg. paint blisters at X	11	7075B Iridite
9B	No change	Same as 9A	Same as 9A		
10 10A	No change	V. Sl. corrosion at X	Mod. corrosion at X Sm. paint blisters at X	8	7075C Iridite
10B	No change	Same as 10A	Mod. corrosion at X Lg. paint blisters at X		
11 11A	No change	V. Sl. corrosion at X	Sl. corrosion at X Sm. paint blisters at X	6	7075B Sulfuric Anodize
11B	No change	Same as 11A	Same as 11A		
12 12A	No change	V. Sl. corrosion at X	Mod. Corrosion at X Sm. paint blisters at X	9	7075C Sulfuric Anodize
12B	No change	Same as 12A	Same as 12A		
13 13A	No change	Sl. corrosion at X Sm. paint blisters at X	Ext. pitting corrosion at X Lg. paint blisters at X	14	7075B Chromic Anodize
13B	V. Sm. paint blisters at X	Same as 13A	Same as 13A		
14 14A	No change	Sl. corrosion at X	Ext. corrosion at X Paint failure at X	16	7075C Chromic Anodize
14B	No change	Same as 14A	Same as 14A		
15 15A	No change	V. Sl. Corrosion at X	Sl. corrosion at X Sm. paint blisters at X	4	7075B Sulfuric Anodize Dichromate Seal
15B	No change	Same as 15A	Sl. corrosion at X Lg. paint blisters at X		
16 16A	No change	No change	V. Sl. corrosion at X	2	7075C Sulfuric Anodize Dichromate Seal
16B	No change	No change	Same as 16A		

CODES: V. - Very; Sl. - Slight; Mod. - Moderate; Ext. - Extensive; Sm. - Small; Lg - Large

CORROSION RATING INDEX: No. 1 - best; No. 16 - poorest (Condition of substrate at X)

* See table for complete alloy and coating specification

6 months at the Florida test site. After exposure, the panels were treated for corrosion using acid cleaner brightener solution meeting MIL-C-5410 requirements, rinsed neutral to litmus paper, and chemically pretreated with MIL-C-5541, Class 1A chemical conversion coating. The new test panel was cut from a retained laboratory control, the alloy and chemical treatment being identical to the Florida exposed test panel.

As illustrated in Figure 17, panels A, B and C were painted with one coat of epoxy primer meeting MIL-P-23377C specification requirements. The entire surface of panel A, and the top half of panel C were topcoated with the NRL (gray) topcoat. The entire surface of panel B and the lower half of panel C were topcoated with the standard MIL-C-81773B (gray) linear urethane topcoat.

Panels A, B and C were scribed to the substrate metal using a sharp metal scribe, then exposed in the NaCl-SO_2 test chamber for 400 hours. The panels were then rinsed thoroughly, dried, photographed and subsequently returned to the NaCl-SO_2 test chamber for an additional 400 hour test period. Figure 17 illustrates the condition of the test panels after an exposure period of 400 hours.

As illustrated by panels A and B in Figure 17, the NRL topcoat and the MIL-C-81773B topcoat, applied to the Florida aged and reworked test panels, exhibit excellent corrosion protective properties. The amount of corrosion, as evidenced by the small paint blisters at the "X" scribe, are comparable. Panel C in Figure 17 compares the corrosion protective properties of the same topcoats applied to a new aluminum substrate. Again, both coatings exhibit similar properties. A close comparison of panel C, with panels A and B, illustrates that the new aluminum substrate, (panel C), exhibits less corrosion at the scribe marks than the reworked test panels A and B.

Figure 18 illustrates the condition of the test panels after the total exposure period of 800 hours in the NaCl-SO_2 test chamber. The conclusion of the test demonstrates that the MIL-C-81773B topcoat (panel B), is at least equal or slightly superior to the NRL fluorinated topcoat (panel A). When applied to the new substrate, the NRL topcoat and the MIL-C-81773B topcoat appear to be equal in corrosion protective properties (see panel C).

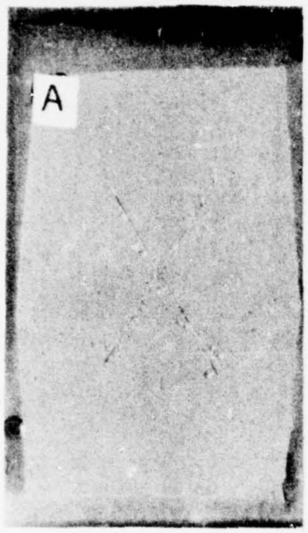
Test No. 3

Selected to obtain data related to the behavior of the topcoats at fastener pattern areas of exterior aircraft skins. The NRL fluorinated gray and MIL-C-81773B urethane gray topcoat finishes were applied to fastener test assemblies prepared as follows:

PANEL A DRY ASSEMBLED (Figure 19) - The top and lower aluminum panels measuring 5 x 8 x 0.125 in. (12.70 x 20.32 x 0.318 cm) were assembled to a backing block measuring 5 x 8 x 0.125 in. (12.70 x 20.32 x 0.318 cm) using steel, cadmium plated structural aircraft fasteners P/N AN 509-10-12. The fasteners were torqued to a value of 25 in.-lbs (2.80 Nm). Following

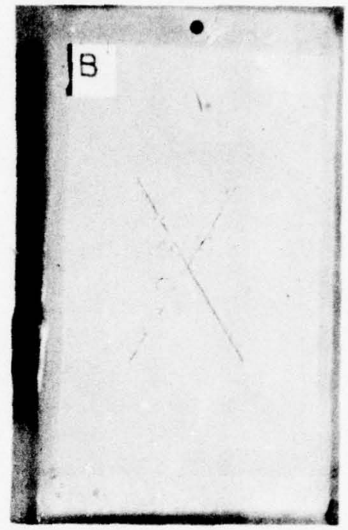
NACL-SO_2 EXPOSURE TEST
EXPOSURE PERIOD - 400 HOURS.

A



FLORIDA
EXPOSED
SUBSTRATES
1-YEAR
REWORKED
AND
PAINTED

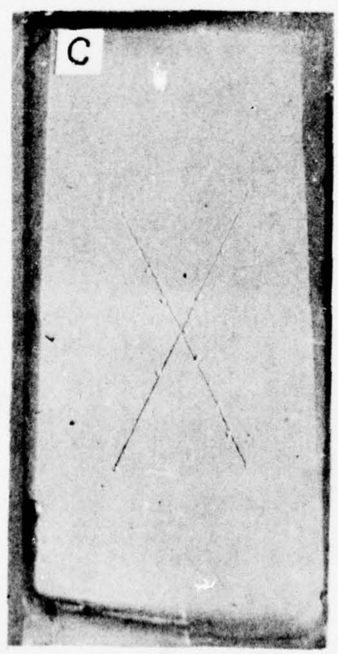
B



EPOXY PRIMER
NRL TOPCOAT

EPOXY PRIMER
URETHANE TOPCOAT

C



NEW
SUBSTRATE

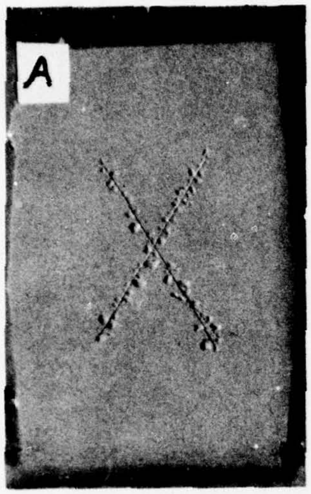
TOP HALF
EPOXY PRIMER
NRL TOPCOAT

BOTTOM HALF
EPOXY PRIMER
IRFTHANE TOPCOAT

FIG 17

NaCL-SO_2 EXPOSURE TEST
EXPOSURE PERIOD-800 HOURS

A

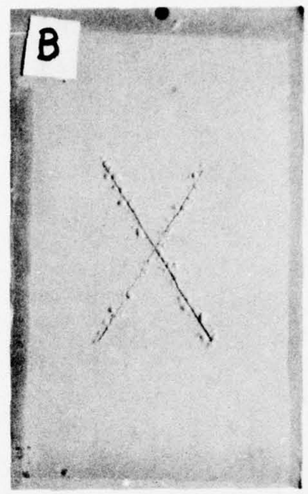


EPOXY PRIMER
NRL TOPCOAT

FLORIDA EXPOSED
SUBSTRATES
ONE YEAR

REWORKED AND PAINTED

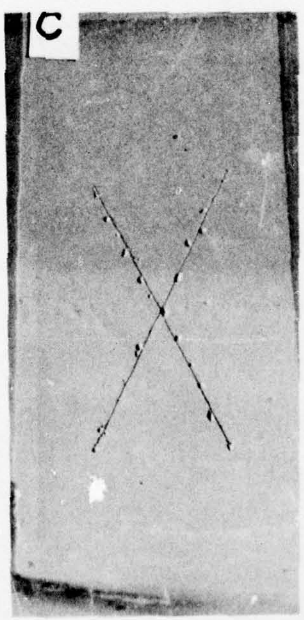
B



EPOXY PRIMER
URETHANE TOPCOAT

C

NEW SUBSTRATE



TOP HALF
EPOXY PRIMER
NRL TOPCOAT

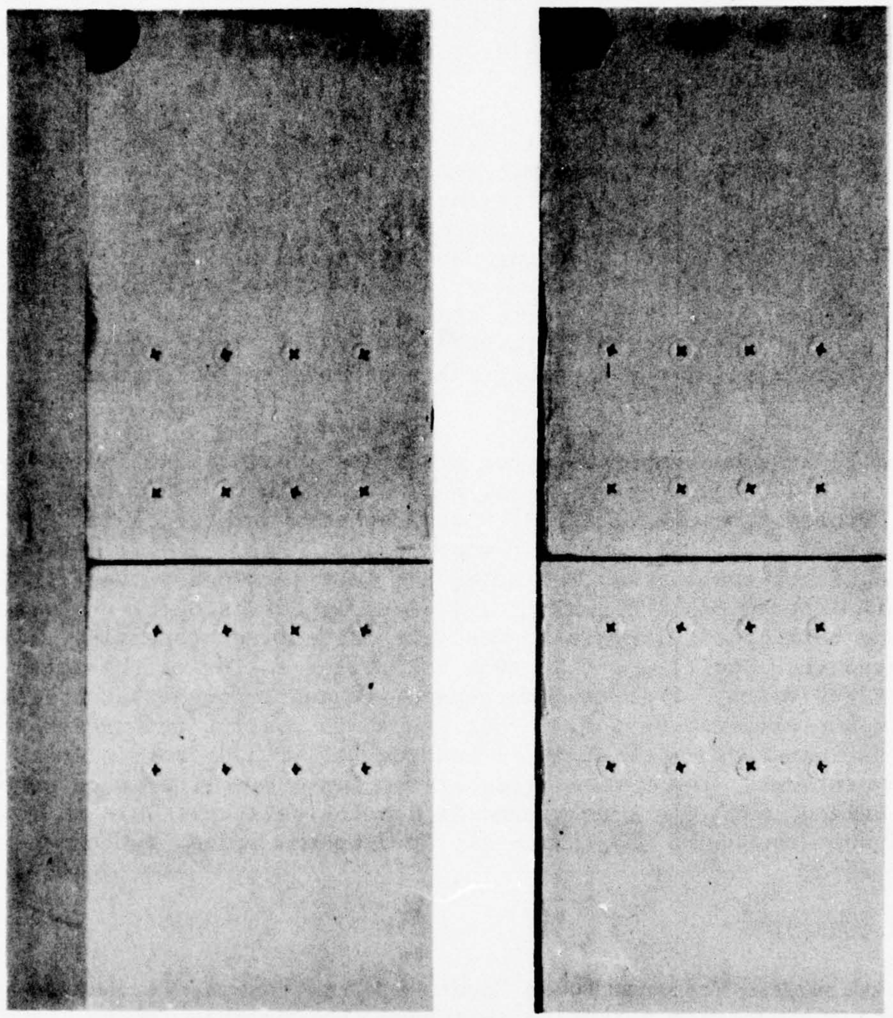
BOTTOM HALF
EPOXY PRIMER
URETHANE TOPCOAT

FIGURE 18

NACL-SO_2 EXPOSURE TEST

EXPOSURE PERIOD-400 HOURS

A B



(DRY ASSEMBLY) (WET ASSEMBLY

TOP PANELS (A B)
EPOXY PRIMER NRL TOPCOAT

BOTTOM PANELS (A B)
EPOXY PRIMER
URETHANE TOFCOAT

FIG 19

assembly, the entire fastener panel was primed using specification MIL-P-23377C primer. After drying for one hour, the top half of each assembly was top-coated with the NRL gray fluorinated topcoat, and the bottom half was coated with the MIL-C-81773B gray specification topcoat. The total film thickness of the applied finishes, primer plus topcoat, averaged between 2.6 to 2.8 mils (0.066 mm to 0.071 mm).

PANEL B WET ASSEMBLED (Figure 19). The mating surfaces of the top and bottom panels and the backing plate were primed with one coat of specification MIL-P-23377C primer. After drying for 12 hours, the panels were assembled to the backing plate by installing the fasteners wet with MIL-P-23377C primer, then torqueing the fasteners to 25 in.-lbs (2.8 Nm). Excess primer was carefully removed using a lint-free cotton cloth dampened with denatured alcohol. The reverse side of the assembly was then primed with one coat of specification MIL-P-23377C primer. After drying for one hour, the face side of the assembly was topcoated in the same manner as panel A.

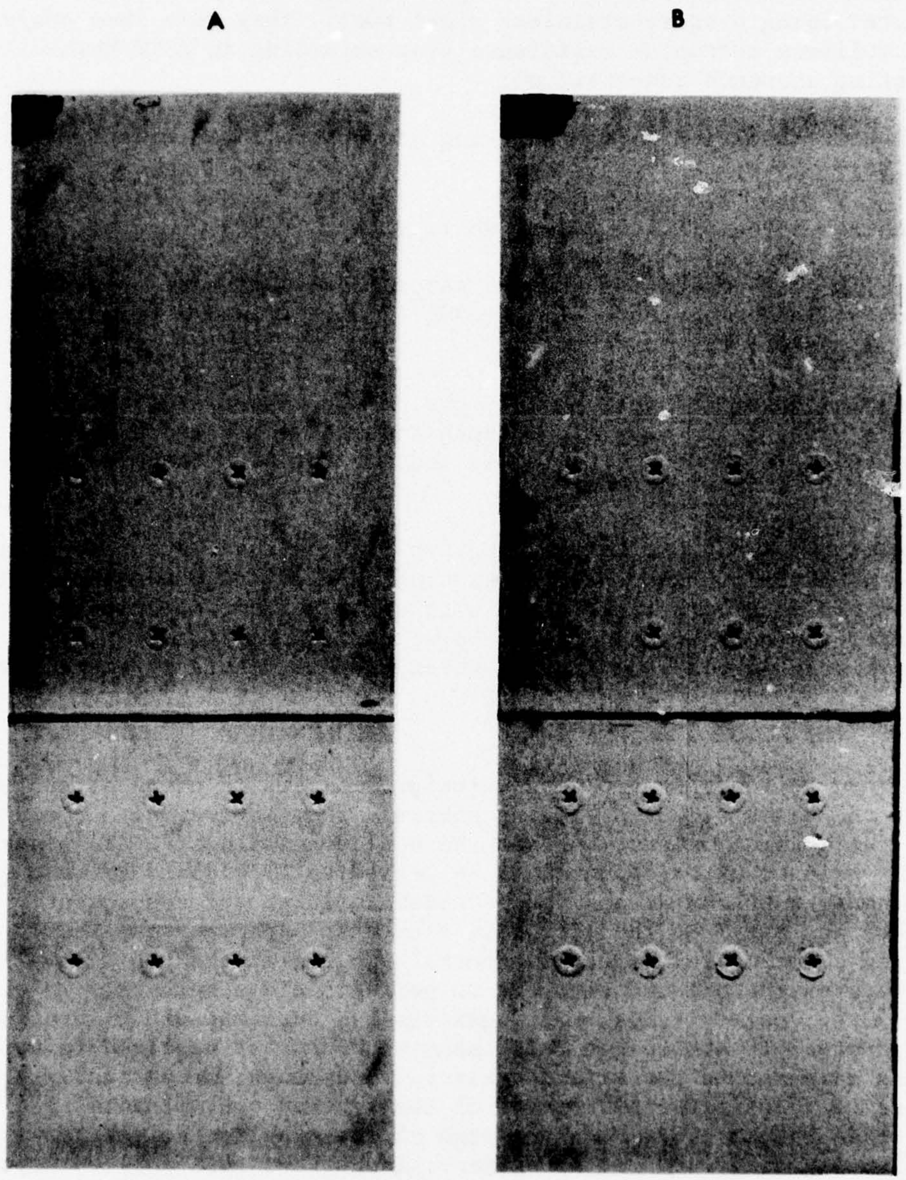
After curing at room temperature for seven days, both A and B panels were exposed for a 400 hour period in the NaCl-SO_2 chamber. They were then removed, rinsed thoroughly, dried, photographed and returned to the test chamber for an additional 400 hour test period. Figure 19 illustrates the condition of the test assemblies after the initial 400 hour test period. Neither panel A nor panel B exhibit any signs of corrosion at the fastener heads, and both coatings exhibit excellent protective properties. Figure 20 illustrates the condition of the test assemblies following the total exposure period of 800 hours. From the photograph, it can be seen that the total 800-hour NaCl-SO_2 exposure period did not result in coating failures. Both assemblies, wet and dry, exhibit no coating failures or corrosion at the fastener patterns. The raised areas at the fastener patterns on panel B (wet installed) should not be viewed as coating failure. This phenomenon occurred when torqueing the fasteners, forcing the primer out of the recessed fastener area.

FILIFORM CORROSION

Filiform corrosion, referred to as "underfilm" corrosion, is characterized by threadlike filaments of corrosion that have considerable length, but little width or depth. Occurring beneath various organic films applied to aluminum substrates, this type of corrosion usually predominates in regions of warm and humid environments.

To obtain filiform corrosion data, the NRL and MIL-C-81773B white pigmented topcoats were applied to 2024 aluminum alloy test panels (3 x 6 x 0.020 in.) (7.62 x 15.24 x 0.51 cm) pretreated with Class 1 chemical conversion coating meeting specification MIL-C-5541 requirements. The painted panels were allowed to cure at room temperature for 7 days.

NaCL-SO_2 EXPOSURE TEST
EXPOSURE PERIOD-800 HOURS



DRY ASSEMBLY WET ASSEMBLY

TOP PANELS (A-B)
EPOXY PRIMER NRL TOPCOAT

BOTTOM PANELS (A-B)
EPOXY PRIMER URETHANE TOPCOAT

FIGURE 20

To initiate filiform corrosion, the panels were scribed with an "X" to the base metal using a sharp stainless steel tool. They were then subjected to the filiform corrosion resistance test according to ASTM Method D2803-70. The testing sequence consisted of:

1. A 4-hour immersion in the salt-fog atmosphere in accordance with ASTM Method B117.

2. Rinsing with distilled water, while wet.

3. Placing in a desiccator above a saturated solution of potassium chromate at a controlled temperature of 77 $\pm$ 3°F (25 $\pm$ 2°C) and a relative humidity of 85 $\pm$ 2 percent for 500 hours.

Upon completion of the test period, the panels were rinsed thoroughly and inspected using a 10X magnifier. Both coatings exhibited excellent protective qualities as no corrosion or coating failures occurred at the scribe marks.

To inspect the substrate metals, the applied coatings were removed using an organic stripper meeting specification MIL-R-81294 requirements. The stripped surfaces were then washed with a one percent solution of a non-ionic detergent, rinsed, dried and examined with a 10X magnifier. It was evident that both test panels were free of threadlike filaments at the scribed area.

SOIL REMOVAL

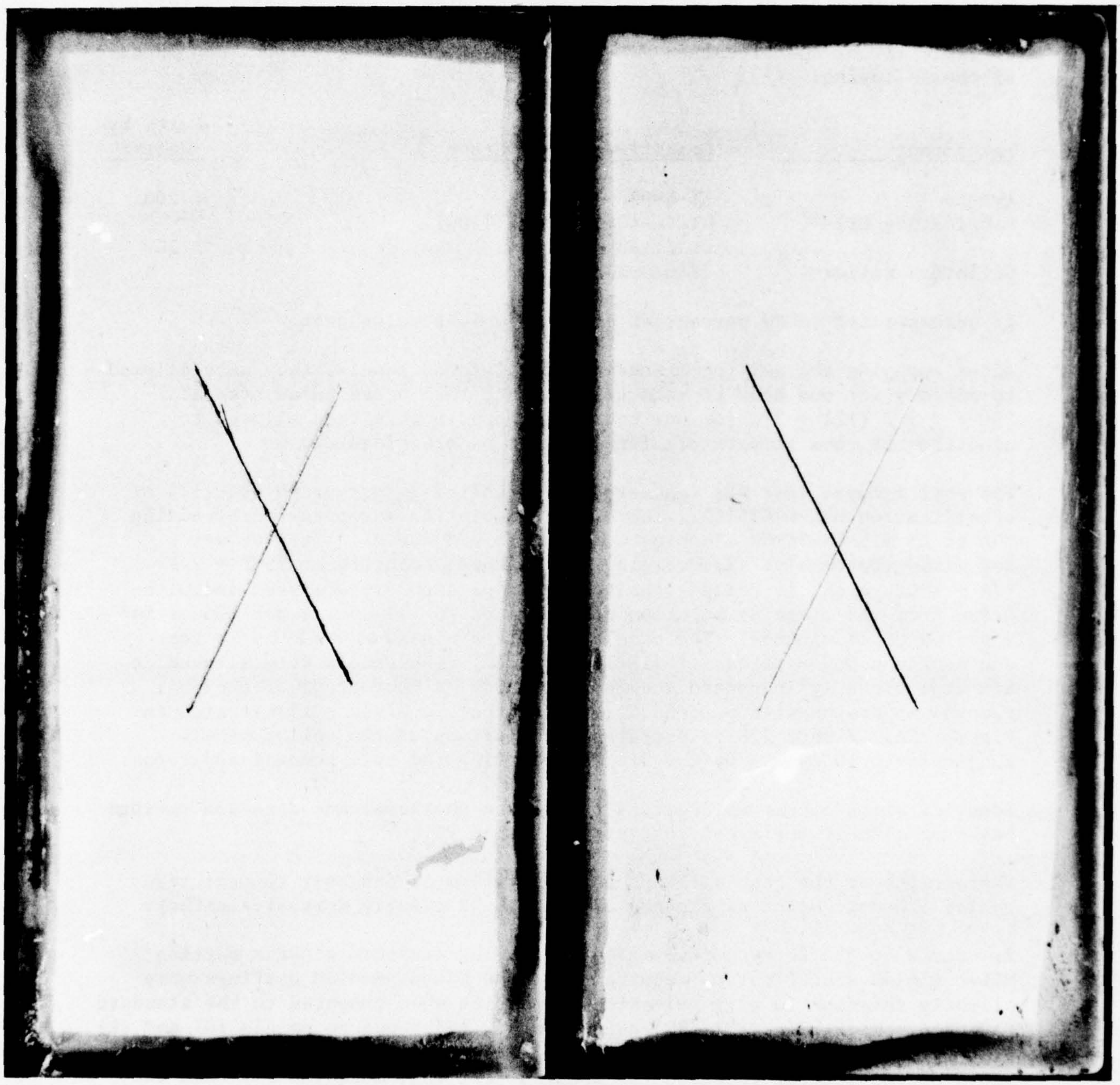
The primary reasons for applying exterior finishes to naval aircraft is to protect the basic structure of the aircraft from corrosion. In order to obtain the maximum protection from the applied coatings, it is essential that the painted exterior surfaces be periodically cleaned to remove foreign contaminants that can attack the protective finish and subsequently expose the substrate metal to the corrosive elements. An important factor in achieving a successful corrosion control program at the Fleet level is the subjection of the painted aircraft to periodic cleaning cycles in order to remove dirt, residual oils, salt, gaseous residues and other foreign airborne contaminants. To accomplish this, many manhours are required to apply the cleaning compound to the exterior aircraft surfaces, mechanically brush the surfaces to facilitate the removal of the adhered contaminants, and finally, water rinse the aircraft surfaces free of the alkaline solvent emulsion type cleaning compound. It is evident, therefore, that applied topcoats that do not readily absorb soils or that easily release soils are very desirable.

The NRL coatings are based on a fluorinated diol that is reported to exhibit soil resisting properties not commonly found in coatings currently being applied to naval and marine aircraft. To substantiate on a laboratory basis the effectiveness of the NRL fluorinated topcoats, and compare it to that of the standard Navy topcoats, the soil removal test outlined in

FILIFORM CORROSION TEST

A

B



EPOXY PRIMER
URETHANE TOPCOAT

EPOXY PRIMER
NRL TOPCOAT

FIGURE 21

military specification MIL-C-43616B was selected as the method for testing. The painted test panels were soiled with a mixture meeting the requirements of Table III of specification MIL-C-43616B. The soiling mixture consisted of the following:

Ingredient	Specification or Grade	Parts by Weight
Xylene	TT-X-916	200
Lubricating Oil 1/	MIL-L-6082 (Grade 1100) Oxidized	200
Colloidal Silica	1160 Grade	4

1/ Concentrated to 30 percent of original weight using heat.

After applying the soiling mixture to the painted panels, they were allowed to air dry for one hour at room temperature, then baked in an oven at 250°F ± 5°F (121 ± 3°C) for one hour. The panels were then allowed to condition at room temperature for 24 hours before cleaning.

The soil removal test was conducted as specified in paragraph 4.4.11.4 of specification MIL-C-43616B. The cleaning solution was prepared by adding 300 cc of MIL-C-43616B cleaning compound to 2700 cc of distilled water and mixed thoroughly. Maintaining the cleaning solution at 75°F ± 2°F (24 ± 1°C), a set of soiled panels were simultaneously immersed and withdrawn from the cleaning solution at a rate of 20 ± 1 cycles per minute for a period of 15 minutes. The panels were then rinsed at a 45° angle for one minute using a stream of distilled water. The panels were allowed to air dry, visually inspected and photographed. A photograph of the soil removal apparatus with suspended (soiled) test panels are illustrated in Figure 22A. Figure 22B illustrates a comparison of two soiled panels subjected to 10 cycles by the dip method using the soil removal apparatus.

Identification of the soiled test panels and the resultant data and ratings based on cleanliness are illustrated in Table VI.

Photographs of the panels taken upon completion of the soil removal test cycles and designated as Figures 23 through 32 clearly demonstrate that:

1. Based on the 20 cycle dip method and using emulsion cleaner meeting MIL-C-43616B specification requirements, the NRL pigmented coatings were slightly inferior in soil releasing properties when compared to the standard topcoats meeting MIL-C-81773B requirements. Reference to panels (K) and (L) Figure 28, and (O) and (P) Figure 30, illustrates that the standard MIL-C-81773B topcoat released the applied test soil more readily than the NRL fluorinated topcoat.

2. The NRL clear, when applied as a protective overlay to the standard acrylic (MIL-L-81352A), epoxy (MIL-C-22750B) and urethane (MIL-C-81773B)

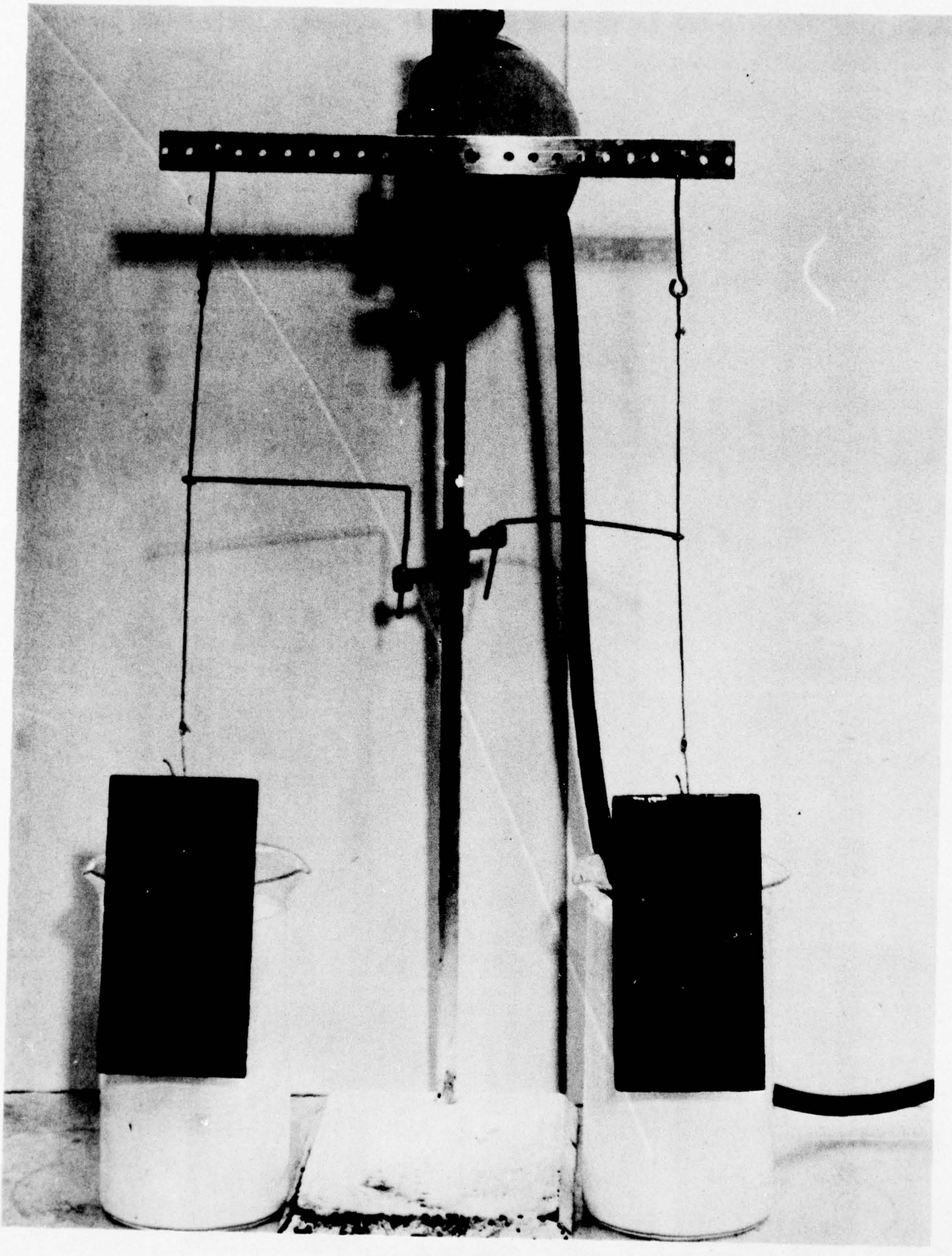


FIGURE 22A

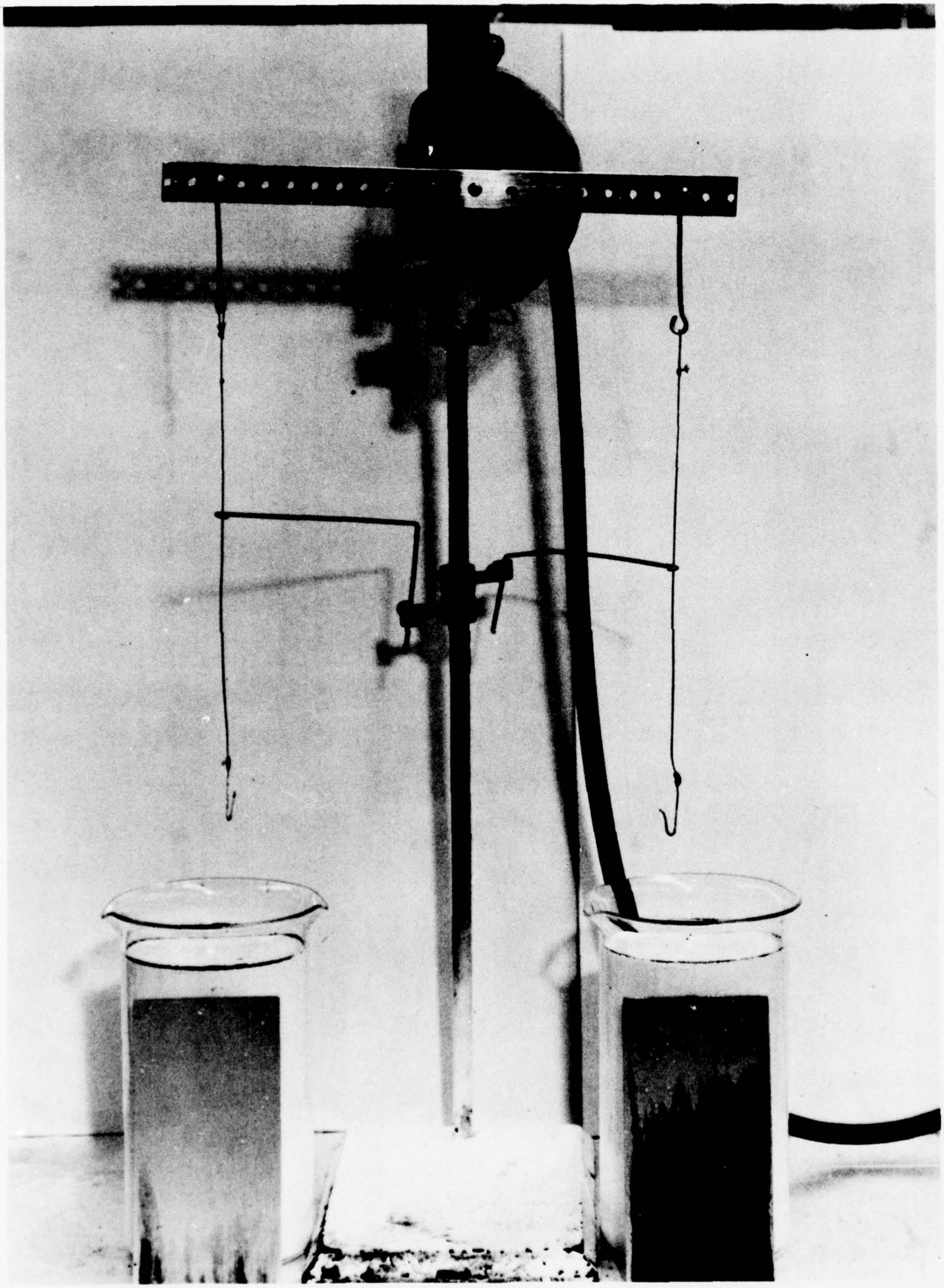


FIGURE 22B

TABLE VI

SOIL RESISTANCE TEST DATA

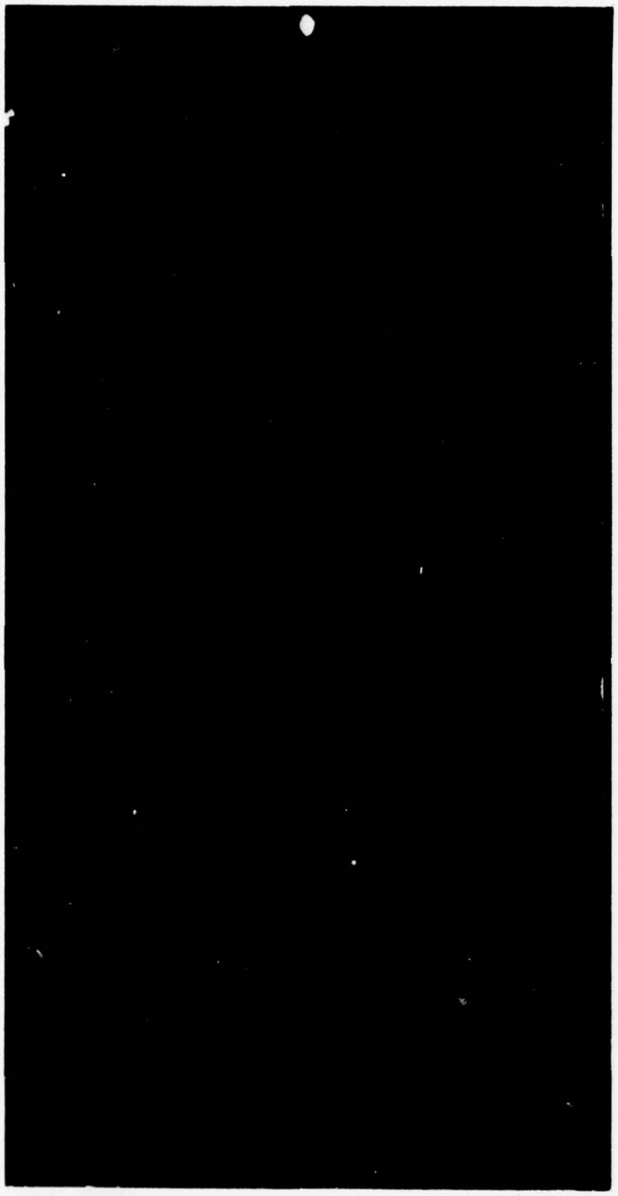
Figure No.	Panel No.	Applied Topcoats	Protective Overcoat	Comments After 20 Cycle per Minute - 15 Minute Cleaning Period	Panel Rating
23	A	MIL-C-81773B (white)	None	Control Panel	----
	B	Same	None	------	12
24	C	MIL-C-81773B (white)	None	Panel D slightly cleaner	5
	D	Same	NRL Clear	than Panel C	2
25	E	MIL-C-22750B (white)	None	Panel E much cleaner than	14
	F	Same	NRL Clear	Panel F	17
26	G	MIL-C-81352A (white)	None	Panel G much cleaner than	1
	H	Same	NRL Clear	Panel H	15
27	I	MIL-C-22750B (gray)	None	Panel I much cleaner than	7
	J	Same	NRL Clear	Panel J	18
28	K	MIL-C-81773B (gray)	None	Panel K slightly cleaner	10
	L	Same	NRL Clear	than Panel L	16
29	M	MIL-L-81352B (gray)	None	Panel M much cleaner than	6
	N	Same	NRL Clear	Panel N	11
30	O	MIL-C-81773B (gray)	None	Panel O much cleaner than	4
	P	Same	NRL Clear	Panel P	9
31	Q	NRL Gray	None	Panel Q slightly cleaner	3
	R	Same	NRL Clear	than Panel R	8
32	S	TEFLON (1)	None	Panel T slightly cleaner	13
	T	NRL Gray	T_1 Top half - None	than Panel S	
			T_2 Lower half - NRL	T_1 half cleaner than T_2 half	----

SPECIFICATION COATINGS:
Gray - Fed. Std. 595, Color No. 16440
White - Fed. Std. 595, Color No. 17875

(1) TEFLON (white) - Proprietary

SOIL RESISTANCE TEST

A



TYPICAL SOILED PANEL
BEFORE CLEANING

B

EPOXY PRIMER MIL-P-23377
TOPCOAT MIL-C-81773 WHITE
OVERCOAT MIL-C-81773 CLEAR

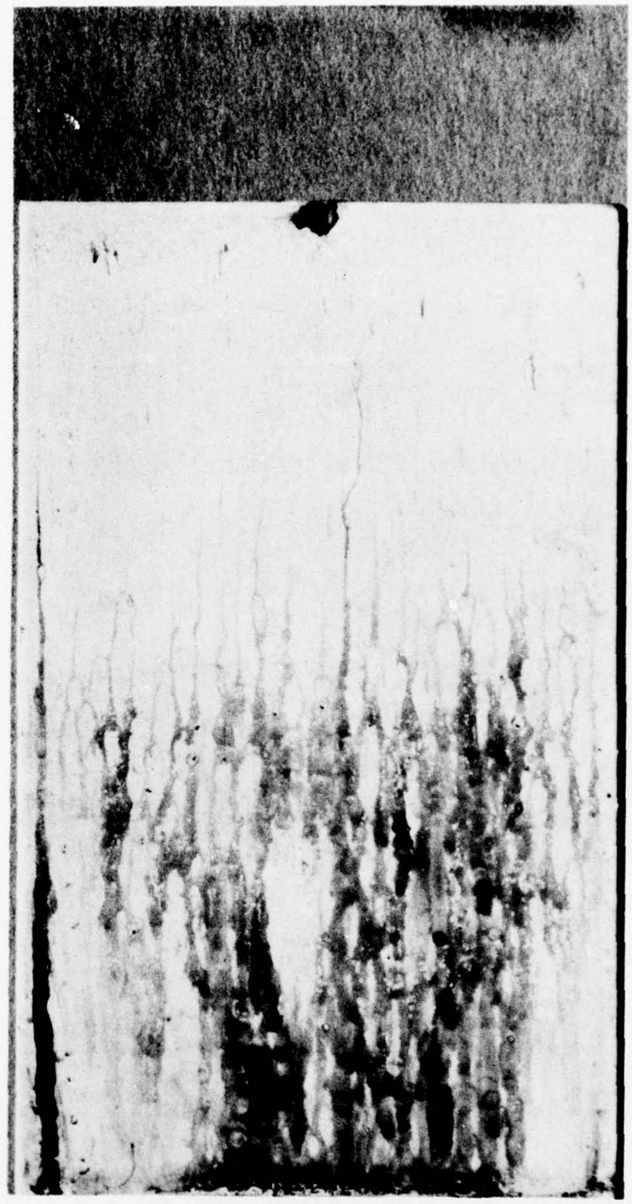
FIGURE 23

SOIL RESISTANCE TEST

C

EPOXY PRIMER MIL-P-23377
TOPCOAT MIL-C-81773 WHITE

D



EPOXY PRIMER MIL-P-23377
TOPCOAT MIL-C-81773 WHITE
OVERCOAT NRL CLEAR

FIGURE 24

SOIL RESISTANCE TEST

E

EPOXY PRIMER MIL-P-23377
TOPCOAT MIL-C-22750 WHITE

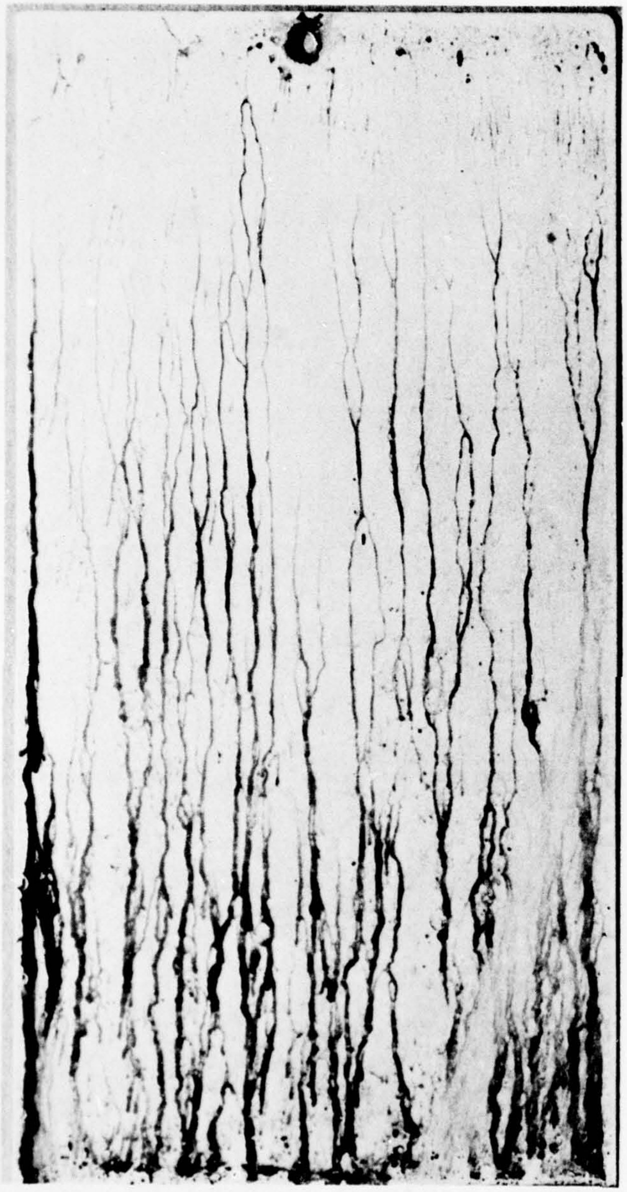
F

EPOXY PRIMER MIL-P-23377
TOPCOAT MIL-C-22750 WHITE
OVERCOAT NRL CLEAR

FIGURE 25

SOIL RESISTANCE TEST

G



EPOXY PRIMER MIL-P-23377
TOPCOAT MIL-L-81352 WHITE

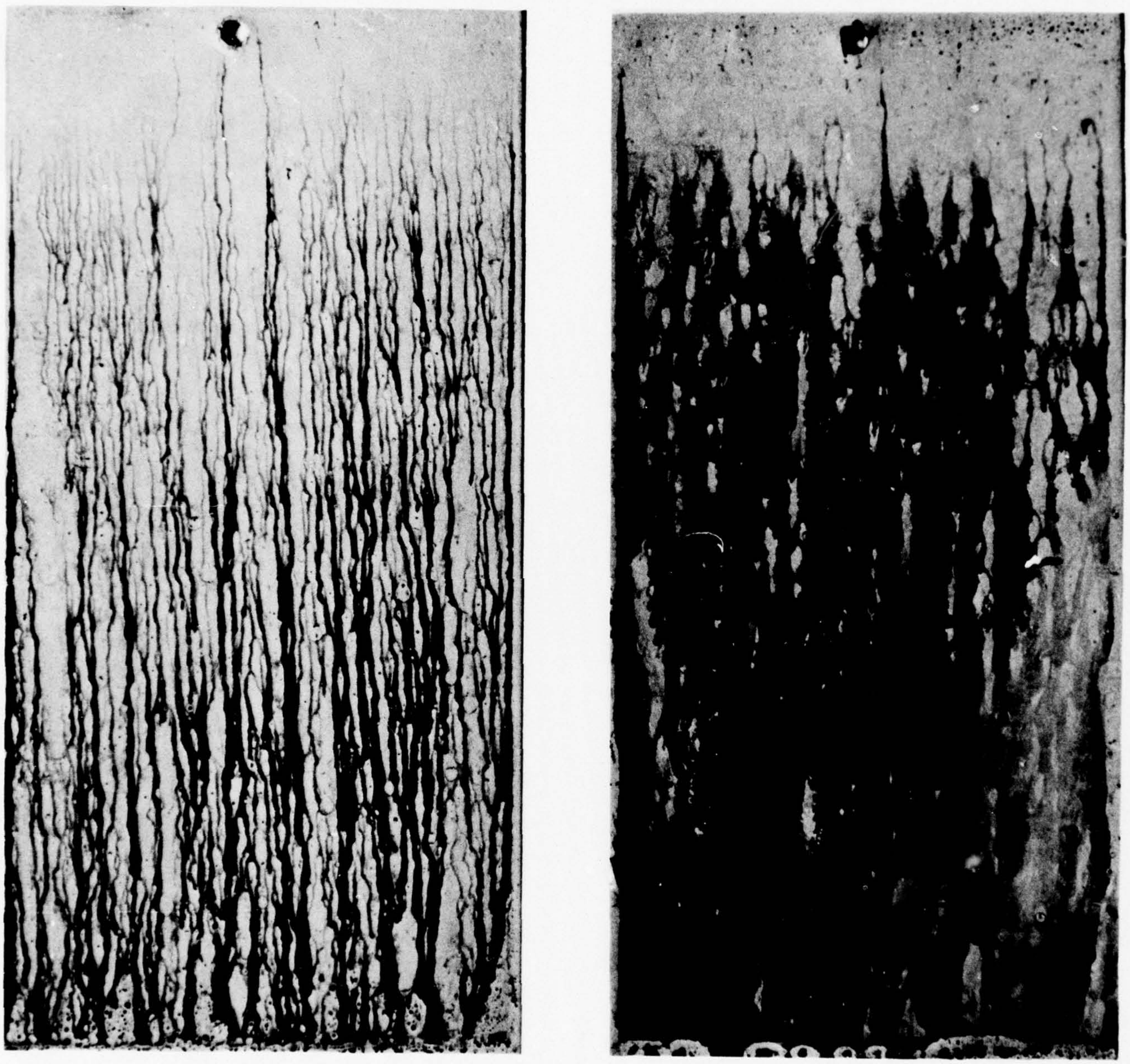
H

EPOXY PRIMER MIL-P-23377
TOPCOAT MIL-L-81352 WHITE
OVERCOAT NRL CLEAR

FIGURE 26

SOIL RESISTANCE TEST

I | J



EPOXY PRIMER MIL-P-23377
TOPCOAT MIL-C-22750 GRAY
(CAMOUFLAGE)

EPOXY PRIMER MIL-P-23377
TOPCOAT MIL-C-22750 GRAY
(CAMOUFLAGE)
OVERCOAT NRL CLEAR

FIGURE 27

SOIL RESISTANCE TEST

K

EPOXY PRIMER MIL-P-23377
TOPCOAT MIL-C-81773 GRAY

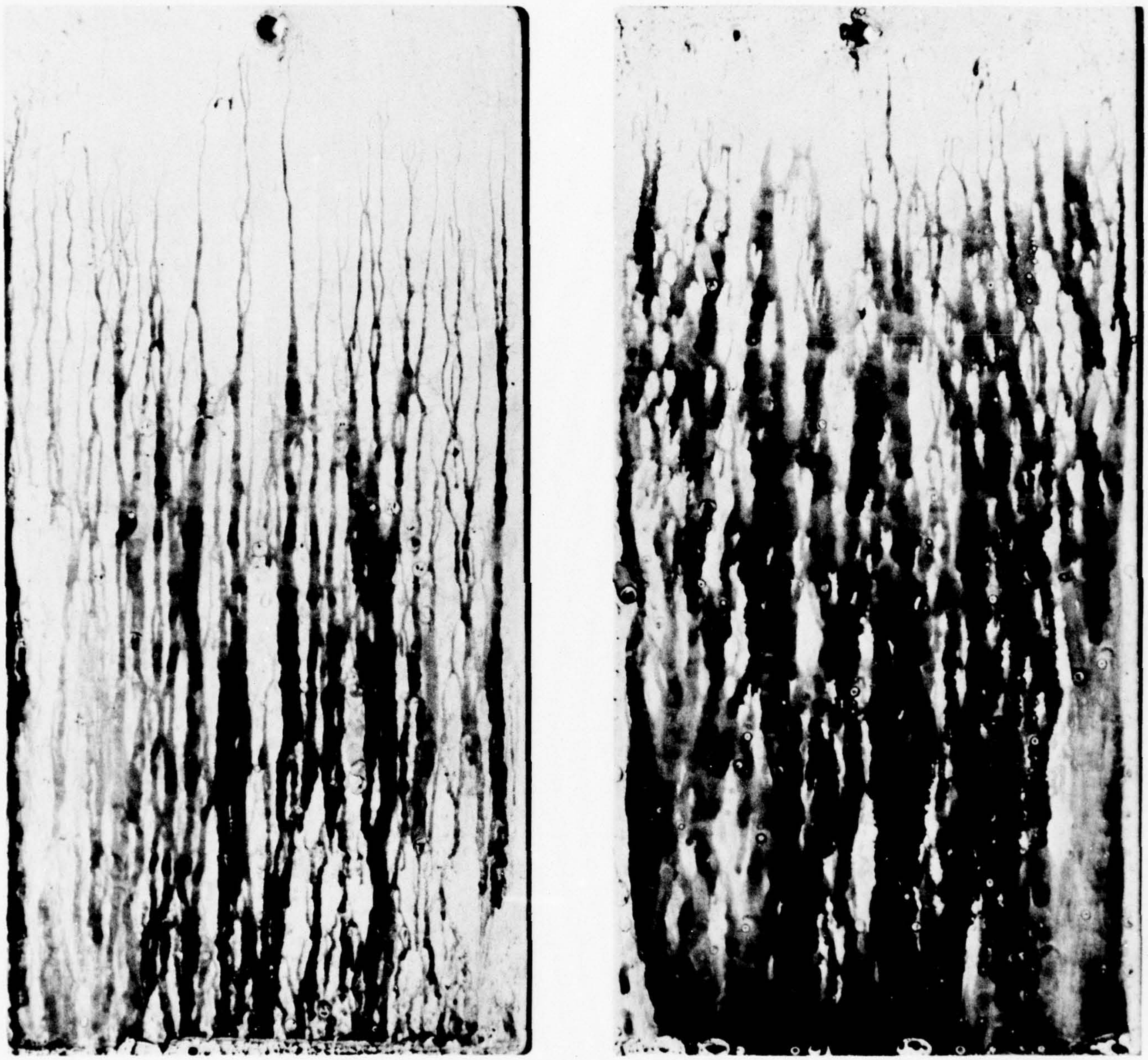
L

EPOXY PRIMER MIL-P-23377
TOPCOAT MIL-C-81773 GRAY
OVERCOAT NRL CLEAR

FIGURE 28

SOIL RESISTANCE TEST

M N



EPOXY PRIMER MIL-P-23377
TOPCOAT MIL-L-81352 GRAY

EPOXY PRIMER MIL-P-23377
TOPCOAT MIL-L-81352 GRAY
OVERCOAT NRL CLEAR

FIGURE 29

SOIL RESISTANCE TEST

O

EPOXY PRIMER MIL-P-23377
TOPCOAT MIL-C-81773 GRAY

P

EPOXY PRIMER MIL-P-23377
TOPCOAT NRL GRAY

FIGURE 30

SOIL RESISTANCE TEST

Q

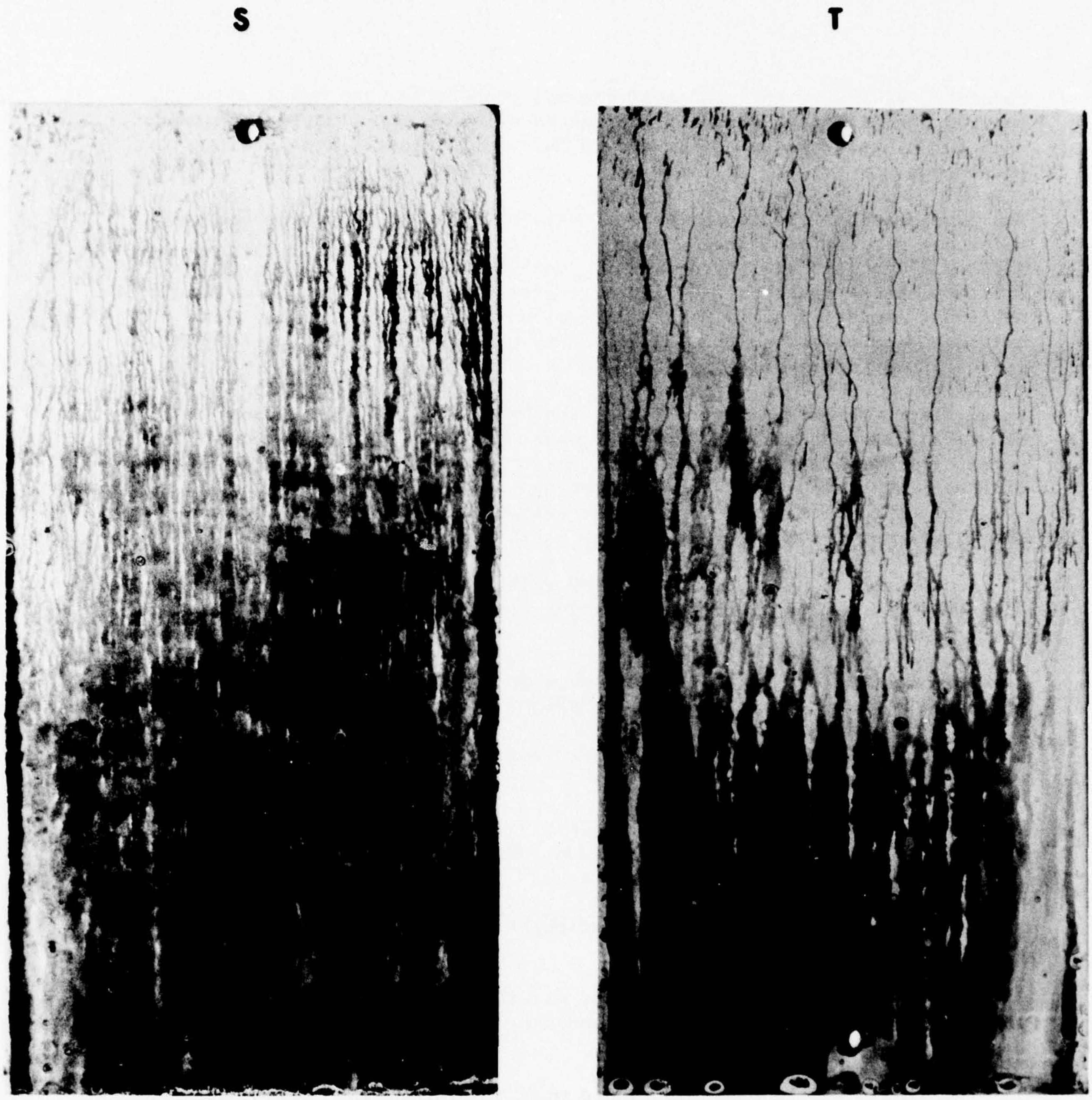
EPOXY PRIMER MIL-P-23377
TOPCOAT NRL GRAY

R

EPOXY PRIMER MIL-P-23377
TOPCOAT NRL GRAY
OVERCOAT NRL CLEAR

FIGURE 31

SOIL RESISTANCE TEST



EPOXY PRIMER MIL-P-23377
TOPCOAT TEFLON WHITE

EPOXY PRIMER MIL-P-23377
TOPCOAT MIL-C-81773 GRAY
OVERCOAT LOWER HALF
NRL CLEAR

FIGURE 32

topcoats, exhibited inferior soil removal properties when compared to the control topcoats that were not overcoated with the NRL fluorinated clear. Each set of test panels in Figures 25 through 30 clearly demonstrates this phenomenon.

The panel ratings listed in Table VI were obtained by comparing the soil releasing properties (cleanliness) of all the tested panels listed in Figures 23 through 32. For example, panel G (Figure 26), topcoated with military specification MIL-L-81352A lacquer was the cleanest panel (retained the least amount of soil), whereas panel J (Figure 27) topcoated with military specification MIL-C-22750B epoxy coating, was the dirtiest panel (retained the most soil).

In an effort to obtain further data, the NRL white pigmented topcoat and the MIL-C-81773B white pigmented topcoat were subjected to an additional experimental soil removal test. The additional test was selected as a means of obtaining cleanability data on coatings subjected to carbon and soot, the type of soil released through jet engine exhausts. A description of the experimental soil deposition test is as follows:

1. Test panels 3 x 6 x 0.20 in. (7.62 x 15.24 x 0.05 cm) were prepared by applying one coat of MIL-P-23377C primer, followed by 2 coats of the topcoat to be tested.

2. The painted test panels were allowed to air dry 24 hours at room temperature, followed by a post cure at 225°F (107°C) for 4 hours.

3. The panels, conditioned to room temperature, were placed paint side down and one inch above the chimney.

4. The alcohol burner, filled with JP-5 fuel meeting military specification MIL-T-5624K, was ignited for 120 seconds. Maximum panel temperature was 160°F (71°C).

5. After the 120-second ignition period, the panels were removed and cooled to room temperature.

6. MIL-C-43616 emulsion foam cleaner was applied from an aerosol spray can, covering the entire panel with an even coat of foam. A 30-second dwell time was allowed.

7. The panels were thoroughly rinsed with a spray bottle filled with distilled water.

8. Steps 6 and 7 were repeated twice and the panels examined visually to determine the amount of soil removal.

Upon completion of a series of soiling tests just described, using the apparatus illustrated in Figure 33, it was apparent that the carbonaceous

EXPERIMENTAL SOIL DEPOSITION APPARATUS (NADC)

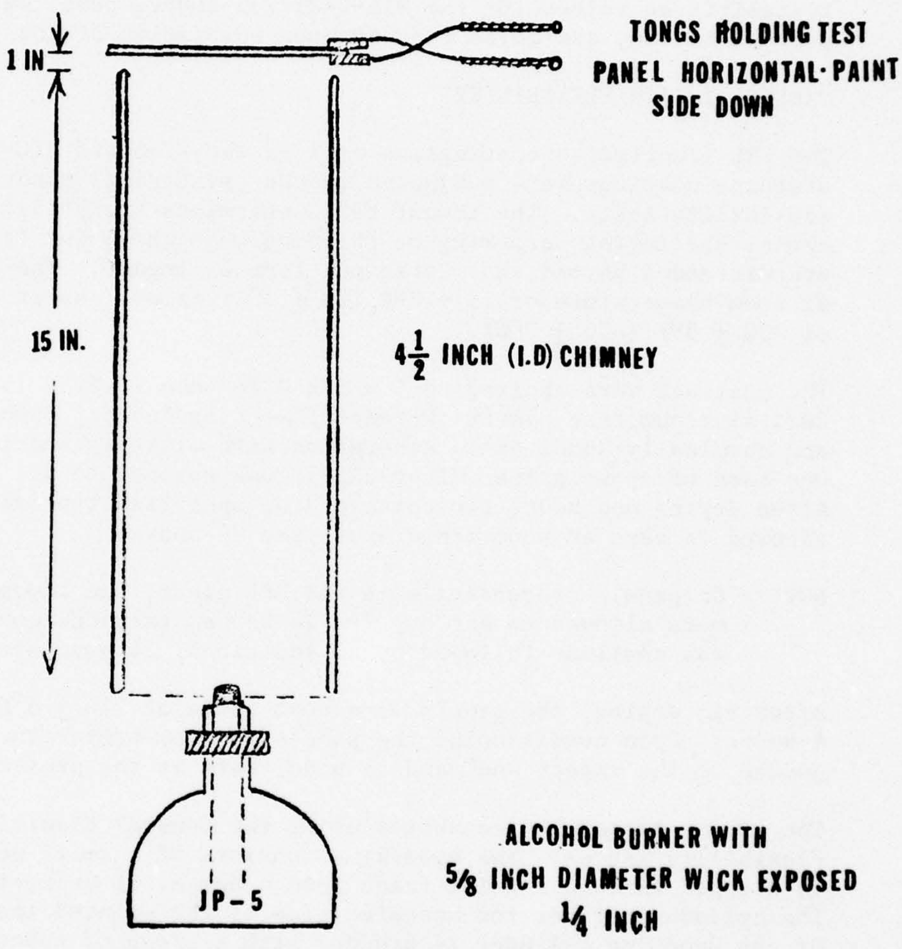


FIGURE 33

deposit from the combustible JP-5 fuel could not be completely removed from either the NRL or the MIL-C-81773B topcoated test panels. Both white coatings retained a film of carbon that could only be removed by mechanically rubbing the coated surfaces with a cotton cloth wet with the MIL-C-43616 cleaning compound.

The transmittance values for the NRL coated panel, before and after the soiling test, were 85.48 percent and 56.20 percent, respectively. The transmittance values for the MIL-C-81773B coated panel was recorded at 90.38 percent before, and 56.58 percent upon completion of the soiling test.

MANDREL-IMPACT FLEXIBILITY

The NRL fluorinated coatings, as well as the standard MIL-C-81773B linear urethane coatings, were subjected to the cylindrical mandrel and impact flexibility tests. The impact test determines the ability of coatings to resist shattering, cracking or chipping when the paint film and substrate are distended beyond their original form by impact. The tests were conducted at room temperature of 73 $\pm$ 2°F (23 $\pm$ 1°C) as well as at a low temperature of -70 $\pm$ 5°F (-56 $\pm$ 3°C).

The coatings were applied to 3 x 6 x 0.20 inch (7.62 x 15.24 x 0.05 cm) 2024 aluminum test panels (O-temper) meeting Federal Specification QQ-A-250/5, and chemically anodized in accordance with military specification MIL-C-8625C. One coat of epoxy primer MIL-P-23377C was applied to all the test panels. After drying one hour, two coats of the specified topcoats were applied and allowed to cure at room temperature for 24 hours.

NOTE: On panels overcoated with the NRL clear, the topcoated test panels were allowed to air dry for 24 hours, then one coat of the NRL clear was applied, followed by an additional 24 hour air dry period.

After air drying, the panels were post cured at 220 $\pm$ 5°F (104 $\pm$ 3°C) for 4 hours. Upon conditioning the panels to room temperature, they were subjected to the impact and mandrel bend tests at the prescribed test conditions.

The impact tests were conducted using the General Electric (G.E.) Impact Flexibility Tester. The apparatus consists of a small metal cylinder which is dropped through a guide track from a height of approximately 4 feet. The cylinder strikes the uncoated side of the painted test panel. Each end of the dropping cylinder is studded with a group of spherical knobs arranged in a circle. When the cylinder strikes the panel, the knobs distend the coating according to the curvature of the respective knob. The knobs are calibrated in terms of percent based on the elongation they produce on the metal panel. The percent draw for the various studs are 1/2, 1, 2, 5, 10, 20, 40 and 60, respectively. After impact the coating is examined under 10X magnification. The stud (elongation) with the greatest draw where no film defects are found is reported as the percent elongation.

The identification of the applied coating systems as well as the results of the mandrel and impact tests are presented in Table VII. The testing data, showing results at room temperature as well as at a temperature of -70°F (-56 ± 3°C), reveals that the flexibility of the NRL and MIL-C-81773B topcoats is similar. When applying the NRL clear as a protective finish to the acrylic (MIL-L-81352A) topcoat and the epoxy (MIL-C-22750B) topcoat, the epoxy coating system increased in percent impact at room temperature from a 10 percent value to a 20 percent value. No increase in flexible properties were noted when either the acrylic or epoxy topcoats, overcoated with the clear NRL finish, were subjected to the low temperature mandrel and impact tests.

FLORIDA EXPOSURE

To obtain weathering data, the selected topcoats were exposed at the Florida test site for periods of 4, 8 and 12 months.

The topcoats were applied to 5 x 16 x 0.020 in. (12.70 x 40.64 x 0.05 cm) aluminum alloy test panels meeting specification QQ-A-250/5 and chromate treated with a chemical conversion coating meeting specification MIL-C-5541B, Class 1A requirements. The standard Navy primer meeting specification MIL-P-23377C was utilized as the primer coat for all of the test panels. The coated test panels were exposed, at the Florida test site, on 45 degree racks, facing south. After the designated exposure periods, the panels were washed lightly with a one percent solution of a non-ionic detergent using a soft cotton swab, rinsed thoroughly with tap water and allowed to air dry. The surfaces were then examined and the 60 degree specular gloss readings recorded. The gloss readings were obtained using the Hunterlab Model D-16 Multipurpose Glossmeter equipped with a digital readout.

Presented in Table VIII are the designated test panels, the applied topcoat finishes and their respective film thickness (primer plus topcoats). Also included are the gloss values before and after the designated exposure period.

Characteristic of the linear urethane topcoats currently being utilized on naval aircraft, test panels CO-32A and CO-35A exhibit high initial gloss values (greater than 90 percent).

After the one-year exposure period, panels CO-32A and CO-35A exhibit excellent gloss retention properties, showing a moderate loss of approximately 20 percent.

The NRL gray pigment topcoat (Panel CO-31) exhibits an initial gloss of 80.8 percent, and a loss of gloss of 12.0 percent after the same one-year exposure period. From this data, it can be concluded that:

1. The MIL-C-81773B topcoat exhibits an initial 60 degree specular gloss that is 12 (plus) percent higher than the NRL pigmented topcoat, and

2. The 60 degree gloss values of the MIL-C-81773B topcoat (gray) and the NRL topcoat (gray) exhibit similar values after an exposure period of one year.

TABLE VII

CYLINDRICAL MANDREL AND G. E. IMPACT TEST DATA

Applied Topcoat Finishes	ROOM TEMPERATURE (73 ± 2°F) (23 ± 1°C) Mandrel 1/8 inch	Bend 1/4 inch	Impact Percent	Film Thickness Mils (MM)	COLD (-70° ± -5°F) (-56° ± -3°C) Mandrel 1/8 inch	Bend 1/4 inch	Impact Percent	Film Thickness Mils (MM)
NRL Clear	Passed	Passed	40	1.8 (0.046)	Fails (FLC)	Passed	1	1.8 (0.046)
NRL White	Passed	Passed	40	2.8 (0.071)	Fails (FLC)	Passed	2	2.8 (0.071)
NRL Gray	Passed	Passed	40	2.8 (0.071)	Fails (FLC)	Passed	2	2.8 (0.071)
MIL-C-81773B White	Passed	Passed	40	2.8 (0.071)	Fails (FLC)	Fails (FLC)	2	2.8 (0.071)
MIL-C-81773B Gray	Passed	Passed	40	2.8 (0.071)	Fails (FLC)	Fails (FLC)	2	2.8 (0.071)
MIL-L-81352A White	Fails (FLC)	Fails (FLC)	1/2	2.6 (0.066)	Fails (FLC)	Fails (FLC)	1/2	2.6 (0.066)
MIL-L-81352A White plus NRL Clear	Passed	Passed	2	3.0 (0.076)	Fails (FLC)	Fails (FLC)	1/2	3.0 (0.076)
MIL-C-22750B White	Passed	Passed	10	2.7 (0.069)	Fails (FLC)	Fails (FLC)	1/2	2.7 (0.069)
MIL-C-22750B White plus NRL Clear	Passed	Passed	20	3.0 (0.076)	Fails (LC)	Fails (LC)	1/2	3.0 (0.076)

CODES: (FLC) - Fine linear cracks - 10X lens (LC) - Linear cracks (no lens required)

CYLINDRICAL MANDREL TEST (180° Bend): Para. 4.6.7 of specification MIL-C-81773B
G. E. IMPACT TEST: Fed. Test Std. No. 141, Method 6226

TABLE VIII

FLORIDA EXPOSURE TEST DATA

Test Panel	Applied Topcoat	Clear Overcoat	Total Film Thickness (Mils)	Total Film Thickness (MM)	60 Degree Gloss Values, Exposure Time (months) 0	4	8	12
CO-31	NRL Gray	----	2.6	(0.066)	80.8	78.8	73.7	68.8
CO-32A	MIL-C-81773B Gray	----	2.7	(0.069)	93.0	86.6	82.5	70.0
CO-32B	MIL-C-81773B Gray	NRL Clear	4.0	(0.102)	80.7	80.4	73.3	67.0
CO-33A	MIL-L-81352A White	----	2.8	(0.071)	70.4	62.7	23.0	12.8
CO-33B	MIL-L-81352A White	NRL Clear	4.5	(0.114)	80.1	65.6	62.0	58.5
CO-34A	MIL-C-22750B White	----	2.7	(0.069)	95.5	35.7	22.0	13.5
CO-34B	MIL-C-22750B White	NRL Clear	4.8	(0.122)	80.2	65.5	61.0	59.5
CO-35A	MIL-C-81773B White	----	2.8	(0.071)	93.4	88.4	84.5	72.2
CO-35B	MIL-C-81773B White	NRL Clear	4.7	(0.119)	82.0	80.8	76.9	70.2

NOTE: NRL White topcoat not included due to shortage of the experimental coating supplied by Naval Research Laboratory, Washington, DC

Test data on the NRL white pigmented topcoat is not illustrated as the coating was not available when the test panels were prepared and submitted for exposure studies.

Test data presented in Table VIII shows the gloss values of the MIL-C-81773B topcoats that were overcoated with the clear NRL coating. Test panels CO-32B and CO-35B illustrate that the NRL clear coating, as expected, lowered the initial gloss of the MIL-C-81773B gray and white topcoats to a value approximating the NRL gray topcoat. The test also demonstrates that the decrease in gloss, after a one-year exposure period, falls into the range of the MIL-C-81773B topcoat finishes (Panels CO-32A and CO-35A) that do not have the NRL clear coating.

Presented in Figure 34(A) are plotted curves of the Florida exposure data, which compares the NRL gray topcoat and the MIL-C-81773B topcoats (with and without an overlay coat of the NRL clear).

Test panel CO-33B demonstrates that by applying the NRL clear coating over the MIL-L-81352A acrylic topcoat, that:

1. The initial gloss has increased to a value of 80.1, approximately 10 percent greater than test panel CO-33A that does not have a clear protective NRL topcoat, and

2. Test panel CO-33B, after a one-year Florida exposure, dropped to a gloss value of 58.5 percent and retained its protective qualities, as the coating did not chalk or weather. Conversely, test panel CO-33A exhibited extensive weathering, as the acrylic coating chalked excessively and dropped to a flat gloss value of 12.8 percent.

Of significant value is a comparison of test panels CO-34A and CO-34B. It can be seen that by applying the NRL clear finish over the MIL-C-22750 epoxy topcoat, that:

1. The initial gloss of Panel CO-34B was lowered to a value of 80.2, approximately 15 percent less than that of Panel CO-34A that does not have the clear NRL topcoat, and

2. As experienced with the MIL-L-81352A acrylic topcoat, test panel CO-34B, after the one-year Florida exposure period, dropped moderately to a gloss value of 59.5 percent and retained its protective qualities. Test panel CO-34A, without the NRL clear topcoat, weathered excessively, as the coating chalked and dropped to a flat gloss of 13.5 percent.

The test results presented in Table VIII, comparing the acrylic MIL-L-81352A and epoxy MIL-C-22750B topcoats, with and without the NRL clear fluorinated overcoats, are graphically presented in Figure 34(B).

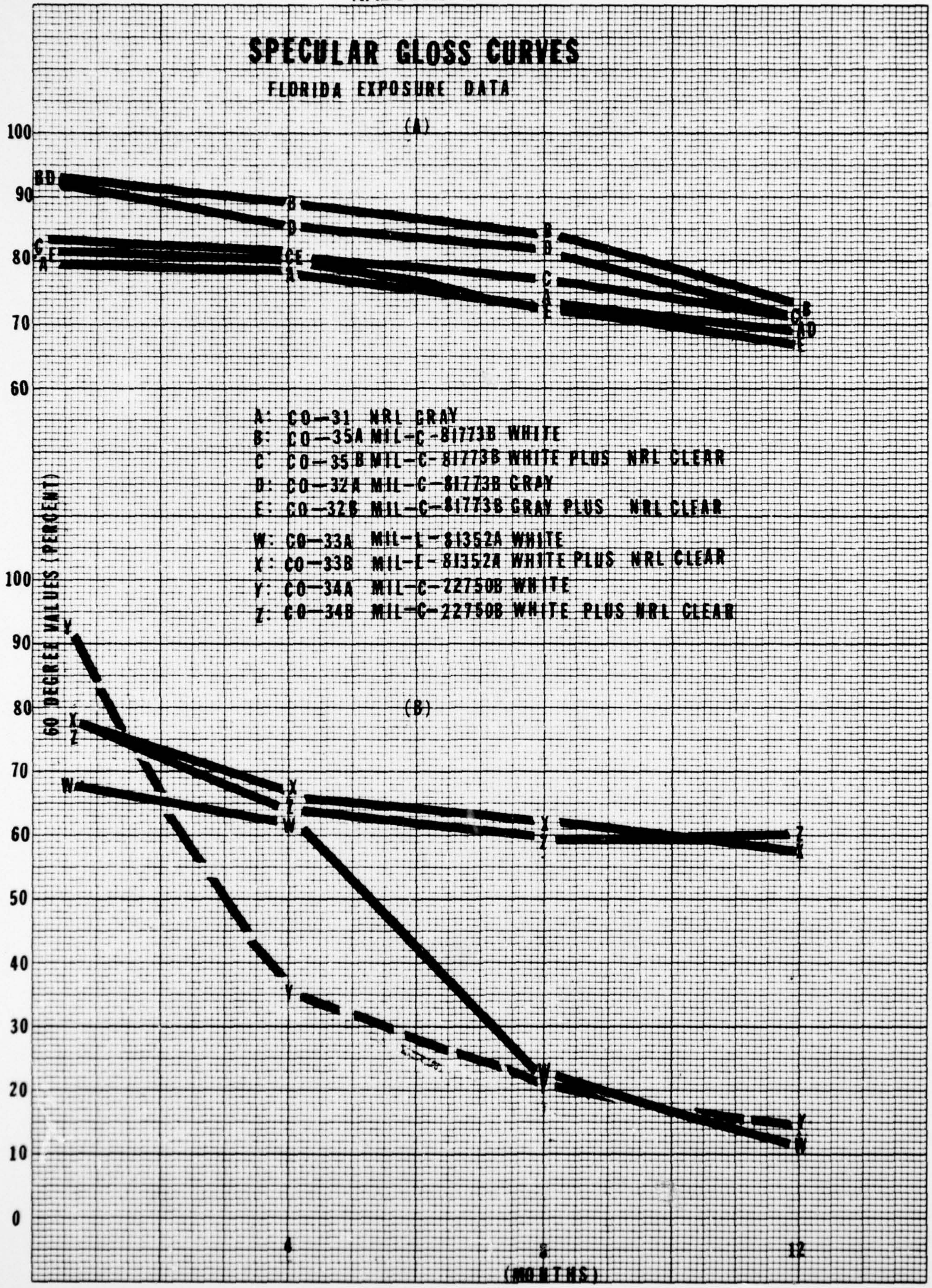

SPECULAR GLOSS CURVES
FLORIDA EXPOSURE DATA
(A)
A: CO—31 NRL GRAY
B: CO—35A MIL-C-81773B WHITE
C: CO—35B MIL-C-81773B WHITE PLUS NRL CLEAR
D: CO—32A MIL-C-81773B GRAY
E: CO—32B MIL-C-81773B GRAY PLUS NRL CLEAR
W: CO—33A MIL-L-81352A WHITE
X: CO—33B MIL-L-81352A WHITE PLUS NRL CLEAR
Y: CO—34A MIL-C-22750B WHITE
Z: CO—34B MIL-C-22750B WHITE PLUS NRL CLEAR
(B)
60 DEGREE VALUES (PERCENT)
(MONTHS)

FIGURE 34(A)(B)

WEATHEROMETER EXPOSURE

The NRL fluorinated coatings, pigmented and clear, were exposed to the Atlas Weatherometer (Model XW) to obtain additional degradation data to be correlated with data obtained from the Florida exposure test.

Newly developed coatings require an outdoor exposure time of one year to properly assess their weathering properties. The XW Weatherometer can provide accelerated testing data to distinguish coatings having good durability from coatings having poor durability.

To correlate the XW Weatherometer test data with the Florida exposure test data, the NRL fluorinated coatings were compared to the Navy MIL-C-81773B urethane, MIL-C-22750B epoxy and the MIL-L-81352A acrylic topcoats.

The substrate test panels measuring 3 x 6 x 0.020 in. (7.62 x 15.24 x 0.05 cm) were 2024 clad aluminum, meeting Federal Specification QQ-A-250/5, and chromate treated with Class 1A finish meeting specification MIL-C-5541B requirements.

All of the test panels were primed with one coat of epoxypolyamide primer meeting military specification MIL-C-23377C requirements, then topcoated with two coats of the specified coating to a total film thickness of 2.6 to 2.8 mils (0.066 to 0.071 mm). The clear overlay coatings were applied to the topcoated panels after they were allowed to air dry seven days. The seven-day delay was utilized as a means of determining the intercoat adhesion properties of the clear coating when applied to the fully cured specification topcoats.

Table IX describes the applied topcoat finishes, with and without the clear overlay coating that were subjected to the XW Weatherometer. Also shown are the specular gloss values before and after each 100 hour exposure period. The accelerated weathering test using the open arc XW Weatherometer equipped with a Corex D filter, was conducted in accordance with Federal Test Standard No. 141a, Method 6151. After each 100 hour exposure period, the test panels were removed and visually inspected. Specular gloss values were recorded using the Hunterlab Model D-16 Multipurpose Glossmeter equipped with a digital readout.

Table IX indicates that the NRL gray and the MIL-C-81773B gray topcoats, after a 600 hour exposure period, exhibit weathering properties comparable to those obtained after the one-year Florida exposure. The initial 60 degree gloss of the MIL-C-81773B gray coating was 12.2 percent higher than the NRL gray topcoat at zero exposure time, and 6.3 percent higher after the 600 hour exposure period.

The MIL-C-81773B white topcoat presents an initial 60 degree gloss of 93.4 percent, whereas the 60 degree gloss of the NRL white topcoat is 72.7 percent, a difference of 20.7 percent. After the 600 hour exposure period, the

TABLE IX

GLOSS VALUES - WEATHEROMETER EXPOSURE TEST DATA

Test Panel	Applied Topcoat	Clear Overcoat	60° Gloss Value EXPOSURE TIME IN HOURS						
			0	100	200	300	400	500	600
1	NRL Gray	----	80.8	79.8	78.2	77.0	76.2	74.2	72.1
2	MIL-C-81773B Gray	----	93.0	88.4	86.4	86.0	85.2	82.2	78.4
3	MIL-C-81773B Gray	NRL Clear	80.7	78.5	78.0	77.7	75.5	70.8	68.2
4	NRL White	----	72.7	72.2	71.8	71.0	69.4	64.5	63.0
5	MIL-C-81773B White	----	93.4	91.9	89.3	86.7	84.3	74.1	65.4
6	MIL-C-81773B White	NRL Clear	82.0	80.1	79.3	78.1	75.0	73.8	70.2
7	MIL-C-81773B White	MIL-C-81773B Clear	93.6	92.8	92.1	91.5	89.6	86.0	84.2
8	MIL-L-81352A White	----	70.4	68.8	60.2	52.7	48.1	42.6	38.0
9	MIL-L-81352A White	NRL Clear	80.1	78.7	75.7	73.6	69.7	69.0	67.2
10	MIL-C-22750B White	----	95.5	93.0	48.5	34.6	26.4	18.0	13.8
11	MIL-C-22750B White	NRL Clear	80.2	78.4	75.8	73.8	69.8	68.2	66.4
12	----	NRL Clear	76.7	76.2	75.0	73.8	70.5	67.2	65.0

MIL-C-81773B white topcoat showed a retained gloss value of 65.4 percent, 2.4 percent higher than the value of the 600 hour exposed NRL white topcoat.

The MIL-C-81773B gray and white topcoats,designated as test panels No. 3 and No. 6 that were overcoated with the NRL clear coating,show a similar change in weathering properties when compared to the control test panels No. 2 and No. 5 which do not have the clear NRL overcoat. The NRL clear, when used as a protective finish,lowers the initial 60 degree gloss values of the MIL-C-81773B gray and white coatings approximately 12.0 percent. This phenomenon was also experienced when conducting the Florida exposure tests.

The test data presented in Table IX also demonstrates that by applying the NRL clear fluorinated coating as a protective finish over the MIL-L-81352A acrylic topcoat, that:

1. The initial 60 degree gloss of test panel No. 9, compared to test panel No. 8, which does not have the NRL clear overcoat, increased approximately 10 percent. This increase in gloss correlates with the test data presented in Table VIII which shows the results of the Florida exposure test.

2. Test panel No. 9 after the 600 hour exposure period, dropped moderately to a 60 degree gloss of 67.2 percent and retained its protective qualities, as the coating did not chalk or weather excessively. Test panel No. 8 exhibited a drop in gloss to a value of 38.0 percent. A comparison with test panels CO-33A and CO-33B in Table VIII indicates that the one-year Florida exposure is more severe than the 600-hour Weatherometer test. However, as illustrated, the XW Weatherometer does provide reliable data that can be correlated with the outdoor Florida exposure test.

Test panels Nos. 10 and 11 demonstrate that, as experienced with the Florida test panels CO-34A and CO-34B (Table VIII), by applying the NRL clear coating over the MIL-C-22750B epoxy topcoat, a trend before and after weathering occurred as follows:

1. The 60 degree gloss value of overcoated test panel No. 11 was decreased to a value of 80.2 percent, 15.3 percent lower than test panel No. 10, which does not have the NRL clear coating, and

2. Test panel No. 11, after weathering, dropped moderately in gloss to a value of 66.4 percent and retained its protective qualities. Test panel No. 10 exhibited excessive weathering, as the epoxy coating chalked and dropped to a flat 60 degree gloss value of 13.8 percent.

To obtain accelerated ageing test data on clear coatings applied as protective finishes, the NRL clear coating, a MIL-C-81773B clear coating and a proprietary clear urethane coating were applied over white urethane (MIL-C-81773B), white epoxy (MIL-C-22750B) and white acrylic (MIL-L-81352A) topcoats. The MEECO Colormaster Model V (Manufacturers Engineering and Equipment Corporation,

Warrington, PA) equipped with a blue filter, was used to determine any color variance upon ageing.

Table X,which lists the selected coatings, their 60 degree specular gloss and reflectance values before and after the 600 hour XW Weatherometer test, indicates that:

1. The NRL clear exhibits a lower initial 60 degree gloss value when compared to the MIL-C-81773B and proprietary clear urethane coating.

2. The NRL clear coating exhibits good to excellent gloss retention after weathering, is greatly superior to the proprietary clear,and is slightly superior to the MIL-C-81773B clear.

3. The NRL clear is superior in ageing properties when compared to the MIL-C-81773B and the proprietary clear coating. As indicated by the reflectance (blue filter values), the NRL clear coating exhibits excellent resistance to yellowing, whereas the MIL-C-81773B clear exhibits good to fair properties. The proprietary clear coating shows the poorest reflectance values as the coating displayed extreme yellowing attributable to coating degradation.

The reflectance values demonstrate that the chemical groupings in the resins, utilized to formulate organic coatings,play a major role in controlling the durable characteristics. For example, epoxide coatings are known to exhibit poor properties when subjected to accelerated weathering, whereas linear urethane coatings show good to excellent weathering properties. Therefore, it is understandable that the NRL clear coating, when applied to MIL-C-81773B urethane topcoats, did not degrade or yellow. When the NRL clear was applied to the MIL-C-22750B epoxy topcoat, a moderate drop in reflectance occurred and the white pigmented undercoat yellowed. It can be assumed that the ultraviolet light (UV), upon long exposure periods,penetrated the clear protective NRL overcoat and degraded the underlying epoxy topcoat, which resulted in the off-white (yellow) condition.

As a conclusion, when selecting a clear coating to be utilized as an exterior protective finish, the ageing characteristics of the underlying coating must be taken into consideration in order to obtain a coating system with good ageing (non-yellowing) properties.

TABLE X

REFLECTANCE VALUES - WEATHEROMETER EXPOSURE TEST DATA

		BEFORE EXPOSURE		600 HOUR EXPOSURE	
White Topcoats	Clear Overcoat	60^{o} Gloss	Reflectance Blue Filter	60^{o} Gloss	Reflectance Blue Filter
NRL	----	72.7	86.28	63.0	82.86
NRL	NRL	72.7	85.50	62.4	82.74
MIL-C-81773B	----	93.4	90.38	65.4	87.70
MIL-C-81773B	NRL	82.0	90.26	70.2	86.68
MIL-C-81773B	MIL-C-81773(AML)	93.3	87.50	84.2	$73.87(Y)_{VS}$
MIL-C-81773B	Proprietary (1)	98.0	87.32	54.7	$56.68(Y)_{E}$
MIL-C-81352(AS)	----	70.4	87.02	38.0	86.86
MIL-C-81352(AS)	NRL	80.1	86.88	68.2	86.50
MIL-C-81352(AS)	MIL-C-81773(AML)	94.3	85.62	80.3	$66.42(Y)_{VS}$
MIL-C-81352(AS)	Proprietary (1)	97.0	82.75	40.1	$58.12(Y)_{E}$
MIL-C-22750B	----	95.6	87.84	13.8	$75.78(Y)_{VS}$
MIL-C-22750B	NRL	80.2	88.50	66.4	$73.70(Y)_{VS}$
MIL-C-22750B	MIL-C-81773(AML)	95.1	87.57	78.8	$66.32(Y)_{VS}$
MIL-C-22750B	Proprietary (1)	98.5	85.60	58.6	$51.78(Y)_{E}$

NOTES: $(Y)_{VS}$ Denotes slight discoloration (yellowing)
$(Y)_{E}$ Denotes extreme discoloration (yellowing)
(1) Proprietary 2-component clear urethane

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(a) Crosslinked Fluoropolymer Coatings, Donald E. Fields and James R. Griffith, Ind. Eng. Chem., Product Research Development, Vol. 14, No. 1, 1975.

(b) Fluorinated Polyepoxy and Polyurethane Coatings, Donald E. Fields, Journal of Coatings Technology, Vol. 48, No. 615, 43, Apr 1976.

APPENDIX A

LIST OF APPLIED COATINGS

AND

MANUFACTURERS

APPLIED TEST COATINGS	MILITARY SPECIFICATION	SOURCE MANUFACTURER
Fluorinated Copolymers	Experimental	Naval Research Laboratory Washington, DC
Gray pigmented	(3-component)	
White pigmented	Same	
Clear	Same	
Epoxy Polyamide	MIL-P-23377C	Andrew Brown Co. Div. of Koppers Co., Inc.
Primer	(2-component)	
Aliphatic Urethanes	MIL-C-81773B	Deft Inc. Chemical Coatings Division
Topcoats	(2-component)	Irvine, CA
Epoxy Polyamide	MIL-C-22750B	Coronado Paint Company Edgewater, FL
Topcoats		
Acrylic Lacquer	MIL-L-81352A	Universal Coatings Newark, NJ
Topcoats		
Aliphatic Urethane	MIL-C-81773B	Naval Air Development Center Warminster, PA
Clear		
Modified Urethane	No MIL spec	Proprietary
Clear		

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Fluorinated polyepoxy and polyurethane base coatings developed by the Naval Research Laboratory, Washington, DC, were evaluated as possible candidate coatings for use on exterior surfaces of naval aircraft.

When laboratory tested against the linear urethane MIL-C-81773B coatings, the fluorinated coatings were found to be lower in initial gloss properties while exhibiting similar properties in adhesion, corrosion

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